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COLORADO STATE UNIVERSITY

FORT COLLINS, COLORADO 80523

FEBRUARY 1977

RENEWAL PROPOSAL

RECEIVED
DEC 19 1977
OFFICE OF
AREA OIL SHALE SUPERVISOR

TO: ENERGY RESEARCH AND DEVELOPMENT ADMINISTRATION

TYPE OF SUPPORT REQUESTED: Research Grant--Renewal Proposal

TITLE OF RESEARCH PROJECT: "Rehabilitation Potential and Practices of Colorado Oil Shale Lands"

PRINCIPAL INVESTIGATOR:
Phillip L. Sims, Ph.D.
Associate Professor
Department of Range Science
Colorado State University
Fort Collins, Colorado 80523
Phone: (303) 491-6541

AMOUNT REQUESTED: $395,249

UNIVERSITY OFFICIAL TO BE CONTACTED REGARDING GRANT OR CONTRACT NEGOTIATION:
M. J. Price
Contracts and Grants Administrator
Office of Sponsored Research
Colorado State University
Fort Collins, Colorado 80523
Telephone: (303) 491-6355

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ABSTRACT

The attached document is a second year renewal proposal to the original research grant (Contract No. E(11-1)-4018) for the period June 1, 1977 to May 31, 1978. The proposed research is the continuation of a program designed to meet the goal of elucidation of guidelines for the rehabilitation potential and practices of Colorado oil shale lands, as stated in the Proposal Supplement of March 1976.

An Intensive Study Site has been selected and several study sites have been developed. As of this time, substantial progress has been made in the microbiological, plant genetics, and plant community succession subprojects. These accomplishments, however, are in their incipiency. As retorted oil shale material becomes available for additional studies, and as further data from ongoing studies is assimilated, rehabilitation guidelines will continue to be defined. The request for construction of the retorted shale experimental plots were outlined in an earlier transmittal dated February 7, 1977.

The research team assembled to carry out this project is basically the same as found in the March 1976 Proposal Supplement. Changes that have occurred are as follows: Dr. Julius Nagy is now part of Dr. Willard Chappell's research team which is involved in the study of trace elements; Drs. Richard Ward and Ralph Dix are responsible for ecological and genetic investigations for shrubs and forbs; and, finally, Dr. Brent Reeves is responsible for mycorrhizal studies.

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INTRODUCTION

Work proposed for the second year of funding will be a continuation of studies proposed in the March 1976 Proposal Supplement. Most studies have been initiated, but some have only completed preparatory investigations because of the unavailability of retorted oil shale material in 1976.

All subprojects will continue in 1977 except for Subproject A. The Resource Management Unit Handbook is near completion and will be ready for publication by June 1, 1977. Therefore, additional funding for this subproject is not requested.

In order to strengthen the objectives of Subproject E two additional studies have been proposed. The first would initiate research into specific ecological requirements for the germination of seeds of important native plants suitable for reclamation purposes. Those requirements would be determined by a series of growth experiments in a controlled environment. The information obtained from this work will be beneficial to the overall success of revegetation in the Piceance Basin. The second would study the interaction of plant species, and cultural practices on a mixture of TOSCO II and Paraho processed shale. The retorted shale mixture would consist of 65% TOSCO and 35% Gas Combustion Process materials as is proposed in Rio Blanco Oil Shale Project's (RBOSP) Detailed Development Plan for Tract C-a. Both studies would conform to the overall objectives of Section E.

PROJECT MANAGEMENT

Dr. Sims will continue to serve as Principal Investigator and Mr. Edward Redente, Senior Research Associate, will continue to assist him in project management related areas. A full-time secretary is presently employed and will assist the Principal Investigator and Research Associate.

The roles of Project Management personnel will be comparative to the responsibilities outlined in the March 1976 Proposal Supplement. These responsibilities relate to overall project management and coordination, scientific and technical soundness of research, interaction with state and federal agencies, coordination of field research activities, preparation of reports, monitoring progress of activities, and fiscal responsibilities.

The research team has and will continue to have periodic discussions to coordinate objectives, research procedures and interact with scientists working on related projects. One such meeting took place on January 13, 1977 and involved ERDA and EPA funded oil shale investigators from CSU and CU along with representatives from industry, state and federal agencies.

Work Plan

A generalized diagram of the activities of the project is shown in Figure 1. More detailed description of project activities is found in the respective subproject sections. Major plot construction will include the establishment of the nitrogen-phosphorus balance plot and processed shale successional test plots. Construction of these plots will extend through the summer as retorted shale is produced and transported to the Intensive Study Site. Microbiological sampling along with plant ecotypic and selection studies will begin in the spring and extend through the fall season. Vegetation sampling on plots established in 1976 will occur throughout the 1977 growing season.

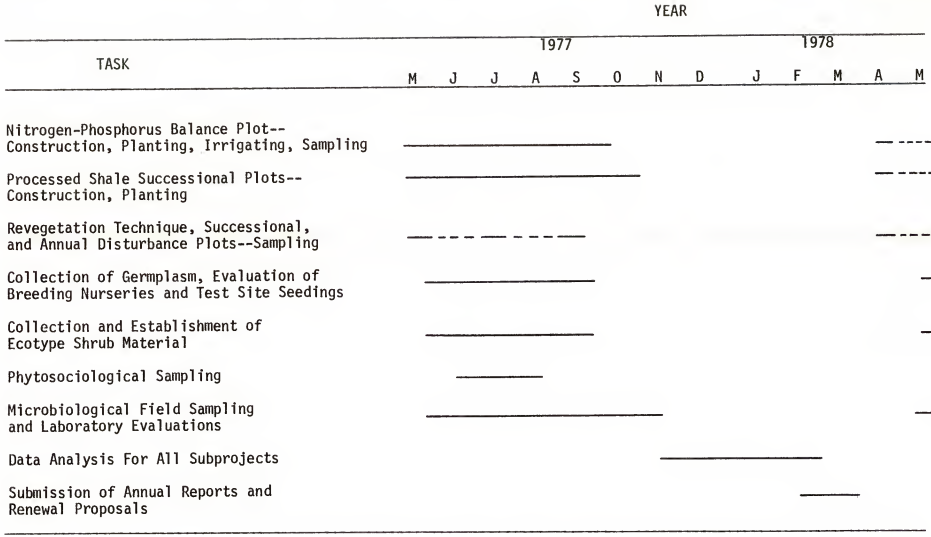

Figure 1. Generalized diagram showing schedule of activities and plan of work (-----preliminary or follow-up study, _____intensive study).

BUDGET SECTION

The Budget Section is divided into two parts. The first section will include Project Management Budget and the second will include the Overall Project Budget. A Supplemental Budget Request was submitted on February 7, 1977 which included major expenditures required for Intensive Study Site development. Therefore, the Project Management Budget included here relates primarily to personnel, publications and travel.

BUDGET

PROJECT MANAGEMENT

A-II (a) REIMBURSABLE PORTION	Year 2
1. SALARIES AND WAGES	
aa. Scientific Discipline Personnel	
* Principal Investigator Phillip L. Sims 100% of time for 2 months @ $2,550 per month	$ 5,100
* Senior Research Associate Edward F. Redente 100% of time for 12 months @ $1300 per month	15,600
bb. Support Personnel	
* Secretarial	8,000
Hourly Labor	5,000
cc. Fringe Benefits	
Public Employees Retirement Association, 10.64% of *	3,054
Total Salaries, Wages and Annuities	36,754
2. INDIRECT COSTS - 64% of salaries, wages, and annuities	23,523
3. PUBLICATIONS AND REPORTS	1,000
4. TRAVEL	
aa. Domestic	
To and from research site	3,000
Scientific meetings	2,500
5. OTHER DIRECT COSTS	
Computer Services	1,500
6. TOTAL DIRECT COSTS	44,754
7. GRAND TOTAL	68,277

OVERALL PROJECT

Total projected cost for the second year is calculated to be $395,249. A total of 129 man-months of scientific discipline personnel are to be devoted to this study during the second year. This includes the principal investigator, 8 co-investigators, 1 post-doctoral assistant, 1 senior research associate, 4 junior research associates, and 9 graduate research assistants. Support personnel will consist of secretarial, research technicians, and hourly labor bringing the total cost for personnel to $182,450. Additional costs are related to supplies and materials, equipment, travel, and indirect costs.

OVERALL PROJECT BUDGET

COLORADO STATE UNIVERSITY
June 1, 1977 to May 31, 1978

A-II (a) REIMBURSABLE PORTION	Year 2
1. SALARIES AND WAGES	
aa. SCIENTIFIC DISCIPLINE PERSONNEL	
*Principal and Co-Investigators 14.5 months	$ 35,635
*Senior Research Associate 12 months @ $1300 per month	15,600
*Junior Research Associates 43.5 months @ $990 per month	43,065
*Post-doctoral Assistant 5 months @ $1100 per month	6,600
9 Graduate Research Assistants, 50% of time @ $4,400 per year	39,600
bb. SUPPORT PERSONNEL	
*Secretarial	8,850
*Research Technician	9,600
Hourly Labor	23,500
cc. FRINGE BENEFITS	
Public Employees Retirement Association 10.64% of *	12,699
PUBLIC EMPLOYEES RETIREMENT ASSOCIATION IS A MANDATORY RETIREMENT PLAN FOR ALL EMPLOYEES OF THE STATE OF COLORADO. AS A RESULT OF RECENT LEGISLATION THE RATE OF CONTRIBUTION IS: 10.64%	
Total Salaries, wages and annuities	195,149

2.	INDIRECT COSTS-64% of Salaries, Wages and Annuities	$ 124,896
	COLORADO STATE UNIVERSITY'S OVERHEAD RATE ON PROPOSALS IS 64% OF SALARIES, WAGES, ANNUITIES, SICK LEAVE, HOLIDAYS AND VACATION. AUDIT WAS PERFORMED AND THE ABOVE PROPOSAL RATE APPROVED BY THE DEPARTMENT OF HEALTH, EDUCATION, AND WELFARE.	
3.	SUPPLIES AND MATERIALS	13,550
**4.	EQUIPMENT	15,755
5.	PUBLICATIONS AND REPORTS	3,800
6.	TRAVEL	
	aa. DOMESTIC	
	To and from research site	21,850
	Scientific Meetings	6,650
7.	OTHER DIRECT COSTS	13,600
8.	TOTAL DIRECT COSTS	270,354
9.	GRAND TOTAL	395,250

**COLORADO STATE UNIVERSITY HEREBY CERTIFIES THAT THE EQUIPMENT REQUESTED FOR PURCHASE (SEE SUBPROJECT BUDGETS) IS NOT REASONABLY AVAILABLE WITHIN THIS INSTITUTION.

A-II (b) ITEMS SIGNIFICANT TO THE PERFORMANCE OF THE PROJECT CONTRIBUTED BY THE UNIVERSITY

None

A-II (c) TIME OF PRINCIPAL INVESTIGATORS CONTRIBUTED BY THE UNIVERSITY

None

INFORMATION CONCERNING INSTITUTION SUBMITTING PROPOSAL

A. This proposal is submitted by COLORADO STATE UNIVERSITY. Contracts and grants that result from this proposal should be made in the name of COLORADO STATE UNIVERSITY.

B. The officials authorized to sign and submit proposals and to negotiate contracts and grants are the following: (1) Harold J. Carroll, (2) Galen E. Frantz, (3) M. J. Price, Contracts and Grants Administrators; and James F. Brown, Director, Office of Sponsored Research

C. Correspondence should be addressed to: COLORADO STATE UNIVERSITY, Fort Collins, Colorado 80523; Attention: Director, Office of Sponsored Research; Telephone: 491-6355; Area Code: 303.

D. The ASSOCIATE VICE PRESIDENT FOR RESEARCH of COLORADO STATE UNIVERSITY, George G. Olson, is authorized to sign contracts or to acknowledge grants.

E. Colorado State University is an agency of the STATE OF COLORADO and enjoys exemption from tort liability.

STATEMENT OF SOLICITING

We hereby certify that we have not employed or retained a company of person (other than a full-time employee) to solicit or secure this contract (grant) and agree to furnish information relating thereto as requested by the Sponsor's cognizant officer.

We certify that the distribution of costs between the direct and indirect categories as shown in the proposal conforms to the usual accounting practices of the institution and to the distribution used by the cognizant federal audit agency.

February 24, 1977
Date

Phillip L. Sims
Dr. Phillip L. Sims
Principal Investigator

C. Wayne Cook
Dr. C. Wayne Cook, Chairman
Department of Range Science

M. J. Price
M. J. Price
Contracts and Grants Administrator

SUBPROJECT B

TITLE: LONG-TERM FERTILITY MAINTENANCE ON LAND DRASTICALLY DISTURBED BY OIL SHALE DEVELOPMENT

PERSONNEL: Dr. William A. Berg, Associate Professor
Dr. Burns A. Sabey, Professor

OBJECTIVES

Long-term fertility requirements and methods of meeting these requirements on deficient soil materials disturbed by oil shale development in northwestern Colorado will be determined.

CONTINUATION PROPOSAL

The following treatments represent the experimental approach to the problem of supplying adequate N and P for vegetation established on the extremely deficient soil materials at the intensive study site:

1. Low to moderate annual applications of inorganic fertilizer N over a four-year period. The annual per-hectare rates are:
   a. 56 kg N
   b. 112 kg N
   c. 224 kg N
   d. 448 kg N

2. High rates of inorganic fertilizer N added only at the initiation of the study. These rates give a total N treatment equal to the summation of the four annual applications in treatment 1. The per-hectare rates are:
   a. 224 kg N
   b. 448 kg N
   c. 896 kg N
   d. 1793 kg N

3. The high N fertilizer rates as in treatment 2 above, plus sawdust

added at the initiation of the study at a rate of (a) 11.2, (b) 22.4, (c) 44.8, and (d) 89.7 metric tons per hectare, respectively.

4. Moderate to high rates of sewage sludge and sawdust added at the initiation of the study. The per-hectare rates on a dry weight basis are:
   a. 56 metric tons sludge
   b. 112 metric tons sludge + 22.4 metric tons sawdust
   c. 224 metric tons sludge + 44.8 metric tons sawdust
5. Phosphorus applications with nitrogen:
   a. 112 kg N/ha + 112 kg P_2O_5 (48 kg P)/ha
   b. 896 kg N/ha + 112 kg P_2O_5 (48 kg P)/ha
   c. 112 kg N/ha + 448 kg P_2O_5 (192 kg P)/ha
   d. 896 kg N/ha + 448 kg P_2O_5 (192 kg P)/ha
6. A check plot receiving no N fertilizer.

These give a total of 20 treatments. The smallest feasible plot size is 4.5 x 9 meters. This should result in an effective plot of about 3 x 7.6 meters when border effects from adjacent treatments are considered. Thus, an area of 836 sq. meters will be needed for one set of treatments. Three replications will be used for a total area requirement of 2,508 sq. meters.

The study will be established on N-deficient soil materials. The climatic regime and elevation at the site is typical of much of the land that may be disturbed by oil shale development.

Earth-moving equipment will be needed to level exposed subsoil or alluvial materials on the site. The site will be worked with a heavy duty rototiller. A sprinkler-irrigation system will be used to establish uniform vegetation stands. This will require a total of about 38 cm of water (1-1/3 acre feet) during the two months after seeding.

A uniform application of P will be broadcast over the N-only plot area and worked in. The rate should be high enough so that there is no plant growth response to the P in the manure or sewage sludge. A rate of 672.5 kg triple superphosphate per hectare should achieve this. The inorganic N fertilizer will be ammonium nitrate, which will be broadcast and then worked into the soil.

Species seeded will be a mixture native to the area, similar to the mixtures used by Harbert and Berg (1974). The work of Sims and Redente (1974) serves as a guide to individual species adapted to the area. Drilling is the seeding method to be used. The area will be mulched with wheat straw at the rate of 4.5 metric tons per hectare, the straw will be crimped into the soil by use of a disc.

Stand counts will be made 30 and 60 days following seeding. Thereafter, stand counts will be made annually in mid-June. Ground cover by living and dead vegetation will be estimated in March and June of each year. Estimates of forage production will also be made. Small quadrats will be clipped for dry matter production and N analysis.

Surface soils in each treatment will be sampled annually to a depth of 15 cm. Plant available phosphorus, nitrate-N, total N, and soluble salts will be determined on the soil samples. Nitrogen will also be determined in samples of the organic wastes so that an overall estimate of the N balance can be made for each treatment. It is thought that in this climatic zone little, if any, N will be leached below plant root depths by natural precipitation. Some N loss to the atmosphere from the sludge is expected.

LITERATURE CITED

Harbert, H. and W. A. Berg. 1974. Vegetative stabilization of spent oil shales. Colorado State University Environmental Resources Center Technical Report 4. 40 p.

Sims, P. L. and E. R. Redente. 1974. Revegetation of disturbed surface soils in various vegetation ecosystems in the Piceance Basin. Colo. State University Environmental Resources Center Technical Report 5. 157 p.

BUDGET
SUBPROJECT B

		Year 2
1.	SALARIES AND WAGES	
	aa. Scientific Discipline Personnel	
	* Co-Investigator B. R. Sabey 100% of time for 1 month	$ 2,200
	* Co-Investigator W. A. Berg 100% of time for 1 month	2,200
	Graduate Research Assistant 50% of time for 12 months	4,400
	bb. Support Personnel	
	* Research Technician	5,600
	Hourly Labor	2,500
	cc. Fringe Benefits	
	Public Employees Retirement Association 10.64% of *	1,064
	Total salaries, wages and annuities	17,964
2.	INDIRECT COSTS	
	64% of salaries, wages, and annuities	11,497
3.	SUPPLIES AND MATERIALS	
	Organic wastes	1,500
	Chemical fertilizer	300
	Seed	300
	Mulch	500
4.	EQUIPMENT	
	Spectrophotometer	2,000
5.	PUBLICATIONS AND REPORTS	200
6.	TRAVEL	
	Domestic (to and from site)	5,000
	Scientific meetings	500

7. OTHER DIRECT COSTS	
Lab supplies	1,000
Lab analysis	3,000
Tractor rental	1,000
8. TOTAL DIRECT COSTS	33,264
9. TOTAL SUBPROJECT COSTS	44,761

SUBPROJECT C

TITLE: THE ROLE OF SOIL MICROORGANISMS AS INDICATORS AND POSSIBLE CONTROLLING FACTORS IN PLANT SUCCESSION PROCESSES ON DISTURBED SOILS

PERSONNEL: Dr. Donald A. Klein, Associate Professor
Dr. James P. Nakas, Research Associate
Nicholas Nagle, Research Technician
Linda Smith, Research Assistant

OBJECTIVES

The objectives of the subproject are to determine the possible responses and changes in non-mycorrhizal soil microorganisms during the reestablishment of plant materials based, when possible, on considerations of the effects of the plant root environment on microbial activities.

CONTINUATION PROPOSAL

Phase I

To evaluate microbial responses and changes in numbers and activity during re-establishment of plant communities on disturbed soils.

For this period, the various revegetation plots at the intensive study site installed during the late fall of 1976 will be used. These include the successional, revegetation technique, and annual disturbance plots. When the spent shale successional plot installation is completed during the summer of 1977, this will be included in the test series.

Job 1-1: Evaluation of soil microbial populations and activities in relation to plant succession.

The following parameters will be followed, as noted in the original proposal for the first year of work:

- Total soil bacteria and actinomycetes using sodium caseinate agar (Anonymous, 1968).
- Fungi, using Rose Bengal Medium (Martin, 1950).
- Nitrification activity, using an ammonium ion-mineral salt solution

added to 40 g portions of soil, followed by analysis for nitrate production of varied incubation times (Aaronson, 1970).

- Nitrogen levels (NO_3).
- Phosphorus levels (inorganic).

The N and P assays will be carried out by cooperating scientists working on related subprojects.

- Dehydrogenase activity using the procedure of Klein, Loh and Goulding (1971).
- Phosphatase activity, using the procedure of Tabatabai and Bremner (1969).
- Fungal versus bacterial contributions to decomposition processes, using procedures of Harrison, Wright and Morita (1970) and Anderson and Domsch (1973).

Job 1-2: Evaluation of plant-associated microbial activities in relation and succession processes.

In comparison with the all-over soil analysis which will be completed under Job 1-1, the work in this phase will be concentrated on the microbial populations which are present on the surface of plant roots, which may more closely reflect plant-related changes in microbial populations and activities. Analysis of the rhizosphere zone microbes of major plants which are being considered for the site will be carried out, including the following:

- Grasses (a) Agropyron smithii, Western wheatgrass
  (b) Oryzopsis hymenoides, Indian ricegrass
  (c) Poa pratensis and hybrids, Kentucky and other bluegrass
  (d) Festuca ovina and F. ovina duriuscula, sheep and hard fescue
- Legumes (a) Lupinus alpestris etc., native lupine

(b) Hedysarum boreale utahensis, Utah sweetvetch

(c) Astragalus cicer, cicer milkvetch

In the rhizosphere, nitrifier populations will be enumerated for selected plants by a MPN Technique (Pramer and Schmidt, 1964; Alexander and Clark, 1965).

The extent of mycorrhizal colonization will be determined using procedures of Klein and Molise (1975), if necessary to supplement the mycorrhizal subproject effort. The goal of the work will be to determine if there are any correlations between inorganic phosphorus availability dynamics and mycorrhizal colonization of grasses with various management techniques.

Job 1-3: Plant microbe relationships--initial survey phases of succession changes in soil characteristics as related to microbial activities.

For this phase of the work, which will be carried out in the early summer of 1978, soil samples taken from the test areas used in Jobs 1-1 and 1-2 will be extracted, using distilled water and ethanol as described by Newman and Norman (1943) and the extracts will be used to determine possible effects on the following processes under standardized laboratory conditions:

- Nitrification, using procedures of Moore and Waid (1971) and Neal (1969).
- Respiration, using a mixed soil inoculum grown on soil extract broth and measuring oxygen utilization in a YSI oxygen probe system (Wu and Klein, 1976).
- Nitrogen fixation, a standard reference soil from the test site will be tested for acetylene reduction capability using distilled water or the desired soil extract by procedures described by Hardy, et. al. (1968).

Phase II

Development of approaches for controlling or modifying plant-microbe interactions to enhance or control the succession process. This work will be initiated in the spring 1978 period.

Based on the available background literature, as summarized by Rice (1974), it appears that plants may cause changes in soil microbiological processes such as nitrification and nitrogen fixation, which may play essential roles in succession processes. The purpose of this work, which will extend into the third year of the project, will be to provide management-related information on these processes.

Job 2-1: Microbiological characteristics of plants representative of succession and climax stages being considered for use in the test plot systems. Major plants which are components of plant mixtures as developed by Dr. Terwilliger in the allelopathy portion of the study will be examined for the following parameters:

- Microbial populations and possible differences between plant types using previously-described cultured techniques.
- Effects of water and ethanol extracts of soil from the various test plants on nitrification activities of standard soil microbial populations.
- Nitrogen fixation activities in the rhizosphere will be assayed using techniques given in Job 1-3.

Job 2-2: Plant material decomposition studies.

Portions of plants from varied successional stages will be allowed to decompose in samples of a standard test soil, to determine if inhibitors of the processes of nitrification, respiration or nitrogen fixation might be

produced or released by specific plant materials.

In both 2-1 and 2-2, water will be passed through containers containing soil and the decomposing plant material samples at bi-weekly intervals and collected for subsequent testing of possible effects on nitrification and nitrogen fixation of standard microbial populations.

Job 2-3: Effects of physical disturbance on the ability of reference climax community soils to influence microbiological activities (only if time permits will work in this area be initiated before May 30, 1978).

If reference or climax soils are found to possess an ability to influence nitrification, respiration or nitrogen fixation, processes, the effects of various types of physical disturbance on these microbiological characteristics of soils will be studied.

Among the physical disturbances which will be tested are the following:

- Sieving to remove plants
- Drying at room temperature or at 55-60^0 C, which might occur with surface soils.
- Periodic wetting and drying of soils on a semi-weekly basis.
- Water saturation of soils.

These tests will be carried out with the assumption that a clearly measurable ability of the climax community soil to influence microbial activities had been detected in the Phase I studies. Based on the previous literature as summarized by Rice (1974) it should be possible to identify a sensitive factor amenable to further study.

Additional Possible Work

If required during the spring of 1978, cooperative soil samplings will be made to coordinate with the research program of Dr. Wildung of Batelle

Northwest, related to analyses of hydrocarbon decomposition products and metal-microbe interactions in spent shale materials. As work has been carried out in the areas of hydrocarbon degradation and metal-microbe interactions in this laboratory such sampling and analysis coordination will complement both of these programs by maximizing data comparability.

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Wu, S-Y, and D. A. Klein. 1976. Starvation Effects on Escherichia coli and Aquatic Bacterial Responses to Nutrient Addition and Secondary Warming Stresses. Appl. and Env. Microbiol. 31:216-220.

BUDGET
SUBPROJECT C

	Year 2
1. SALARIES AND WAGES	
aa. Scientific Discipline Personnel	
*Co-Investigator D. A. Klein 100% of time for 2½ months @ $2,600/month	$ 6,500
*Post-doctoral Assistant 50% of time for 12 months @ $550/month	6,600
Graduate Research Assistant 50% of time for 12 months	4,400
bb. Support Personnel	
*Technician ½ time	4,000
1 hourly Assistant	2,000
cc. Fringe Benefits	
Public Employees Retirement Association 10.64% of *	1,819
Total salaries, wages and annuities	25,319
2. INDIRECT COSTS	
64% of salaries, wages and annuities	16,204
3. SUPPLIES AND MATERIALS	
Significant Items of a Special Nature:	
Radiotracer materials	500
Scintillation Supplies	400
Other supplies:	
Routine glassware	500
General chemicals	800
Media	900
4. EQUIPMENT	
In excess of $1,000:	
Digital pH Meter--Northrup (for use in nitrate determination)	1,300
Other equipment:	
Lab-Top Shaker	600
Replacement Nitrate electrodes (2 sets)	600
Misc. equipment repair parts	605

5. PUBLICATIONS	300
6. TRAVEL	
Domestic (to and from research site)	850
Scientific meetings	1,050
7. OTHER DIRECT COSTS	
Greenhouse expenses	500
8. TOTAL DIRECT COSTS	34,224
9. TOTAL PROJECT COSTS	50,428

SUBPROJECT D(A)

TITLE: SELECTIVE BREEDING OF GRASSES, LEGUMES, AND FORBS TO DEVELOP IMPROVED STRAINS THAT CAN BE ESTABLISHED ON DISTURBED SITES IN OIL SHALE AREAS TO PRODUCE A STABILIZED ECOLOGICAL COMMUNITY.

PERSONNEL: Dr. Robin Cuany, Associate Professor
Mr. Walter Padilla, Research Assistant

OBJECTIVES

Research on selection and breeding of plant materials is programmed along the lines of the five objectives as stated in the original proposal:

1) To collect and assemble germplasm sources
2) Evaluation of spaced plants in two nurseries, and clonal propagules or progenies under controlled stress - salinity.
3) Evaluation of seeded progenies in intensive site and satellite field plantings
4) To use suitable breeding procedures for recombination and progeny testing to develop improved strains
5) To coordinate research on best means of multiplying and planting improved strains.

Certain items which it was not possible to explore in the first budget year will receive new emphasis. Additional personnel to be added for the next project year will enable us to study a more reasonable number of species to meet the above five objectives.

CONTINUATION PROPOSAL:

1. Germplasm sources

The major collecting of ecologically relevant sites has already been done for western wheatgrass and Indian ricegrass; therefore, collecting of grasses will emphasize one or two types of fine-leaved fescues of the Festuca ovina--arizonica-idahoensis group. Some accessions will be local collections and some

will be sought by correspondence, and likewise for usable strains of Poa pratensis or its interspecific crosses studied at the Carnegie Institution of Washington, Stanford, California.

For the legumes, our collecting will emphasize the native lupines below 2,286 meters and several locations for Utah sweetvetch, so as to cover the range of genecological variation for both these species. We will continue to receive breeding lines of the introduced species Astragalus cicer from the USDA-ARS.

Initiation of systematic collection of other forbs will start for two or three species from among the genera Balsamorhiza, Osmorhiza, Penstemon or Sphaeralcea. The precise choice will be made in light of data from existing trial plots and the ecology of disturbed areas, with attention to relative status of their mycorrhizal associations.

2. Maintenance and evaluation of breeding nurseries

Four existing nurseries of Agropyron smithii (two each at Fort Collins and Meeker) and two of Oryzopsis hymenoides will be maintained for type observation and growth habit comparison, including vigor and vegetative spread. Genetic variability measured within versus among sources is used to calculate heritability of various characters, and the seed and vegetative propagules from desirable plants are used as parent stock for breeding advancement, parallel with or subsequent to individual-plant progeny tests of various kinds. Screening of progeny for germination under salinity stress will continue, and promises the chance of breeding wheatgrass or ricegrass strains with higher salinity tolerance, as may be needed for effective rehabilitation of retorted oil shale and some disturbed soils.

Vegetative material from these nurseries will be supplied to the sub-projects on microbial decomposition and mycorrhizal relationships. Seed harvests in 1977 from the newer nurseries will be needed for objective 3 (below).

We expect also to make a feasibility test on establishing western wheatgrass in critical areas by planting sprigs rather than sowing seed.

New nurseries will be initiated for lupines, Utah sweetvetch, other forbs, and possibly fine-leaf fescues, in Summer 1977. Some of these nurseries would have to be delayed until Spring 1978 if either the external source or the collection date make 1977 planting impossible. The nitrogen-fixing status of currently available sources (in the greenhouse) or forthcoming accessions of the legumes will be assessed cooperatively with other researchers.

3. Evaluation of test site seeding performance

Tests established in Fall 1976 at the intensive site and the mountain browse site will be evaluated for germination and vigor in May or June 1977, and for survival and growth in Fall 1977. We must also rate performance during the second growing season (1978). New tests will be seeded in Fall 1977 which incorporate more progenies from the breeding nursery (which were not available last fall) and will provide better representation of the several species under detailed study. In consultation with other project personnel, one or two additional test plot sites will be chosen in ecological zones different from the 20 hectare intensive study site. The 1977 seeding sites will be representative of the oil shale region and encompass the widest possible range of germplasm variation of the various plant materials being studied.

4. Continuation of breeding procedures for recombination

Choice of elite parent plants based on phenotype, visible appearance in the nurseries, ecotype, and seed-setting ability will be started in Spring 1977 and continue into 1978. Choices have to be based also on test-site performance in 1977 and Spring 1978. Although the latter date will be too late for transplanting parent plants into a recombination block, it is possible to control pollination in 1978 by cutting off flowering culms of undesired plants

in the various breeding nurseries. The definitive establishment of replicated clonal pieces of elite parents into crossing blocks should then follow in Fall 1978, with intercrossed seed to be harvested in 1979. Some greenhouse crossing will be tried.

We expect to place 10 to 50 parent plants in the recombination block for each new synthetic variety of each species. This may mean, as an example, two synthetics of western wheatgrass bred for improved seed-set and seedling vigor but adapted to two different ecological zones of the Piceance Basin. In addition, we propose to set up at least one special-purpose synthetic from seedlings tolerant to high salinity, which might serve several ecological zones. It is impractical to expect to release more than five new types of a given species, because of the relatively small demand for commercial seed increase of each one.

5. Seed production methodology

Controlled seed harvest will be conducted at the Fruita and Meeker nurseries in Summer 1977, by both the combine-harvester and hand harvest method. These harvest will provide the basis for determining best methods for breeding and selection of plants that will meet the important criteria of high seed yield and harvestability. A seed source that cannot be provided commercially will not likely become a part of large-scale rehabilitation specifications.

BUDGET
SUBPROJECT D(A)

	Year 2
1. SALARIES AND WAGES	
aa. Scientific Discipline Personnel	
*Co-Investigator, R. L. Cuany 100% of time for 2 months	$ 3,700
*Junior Research Associate 100% of time for 12 months	11,880
Graduate Research Assistant 50% of time for 12 months	4,400
Graduate Research Assistant 50% of time for 12 months	4,400
bb. Support Personnel	
Hourly Labor	3,000
cc. Fringe Benefits	
10.64% of *	1,658
Total salaries, wages, and annuities	29,038
2. INDIRECT COSTS	
64% of salaries, wages, and annuities	18,584
3. SUPPLIES AND MATERIALS	
Greenhouse supplies	400
Seed harvest packets and boxes	200
Field stakes, etc.	200
Chemicals for greenhouse and field	100
Pollinating Bags	100
4. PUBLICATIONS AND REPORTS	100
5. TRAVEL	
To and from research site	4,000
Scientific meetings	500
6. OTHER DIRECT COSTS	
Tractor rental	1,000
Computer	200

7.	TOTAL DIRECT COSTS	$ 35,838
8.	TOTAL SUBPROJECT COSTS	54,422

SUBPROJECT D(B)

TITLE: ECOLOGICAL-GENETIC VARIATION IN IMPORTANT NATIVE SHRUB SPECIES AND ITS INTEGRATION WITH LANDSCAPE-VEGETATION PATTERNS

PERSONNEL: Dr. Richard T. Ward, Professor
Dr. Ralph L. Dix, Professor
William Slauson, Research Associate

OBJECTIVES

There are two major objectives in this study:

1. analysis of ecotypic variation in selected shrub species
2. quantitative phytosociological description of the vegetation of the Piceance Basin.

Both are design to be pertinent to understanding reclamation and to be of use in reclamation plans. The latter will also provide the vegetation framework for ecotype and selection studies. What follows here is a summary of the current status of our investigations and a presentation of the proposed next stages of study.

CONTINUATION PROPOSAL

Ecotype Study

The general strategy for discovering if variation among populations of possible ecological significance has a genetic base or is due to plasticity of expression of a common genotype is to grow, in a common environment, materials collected from different populations. Further, it is advisable to use vegetative materials from the natural environments rather than seeds for propagation in the common garden, since the vegetative material is certain to be representative of a genotype that is adapted to that environment, while all possible recombinants represented by seed may not be so. Future studies to compare the variation within seed populations with variation in surviving plants are anticipated.

Initially a single common garden for propagation and comparison of different source materials is planned and will be located within the Intensive Study Site in the Piceance Basin. Additional plantings of the studied shrubs will be made at the Meeker Plant Materials Center to be used for replacing damaged or inviable plants in the main garden. Other gardens and selected back transplants may be established in the future, however, this is not a pressing need since our experience in other ecotype studies indicates that similar response trends are displayed in multiple gardens.

Due to the length of time required to establish a garden of shrub species and anticipating a lengthy period of measurement taking before even any preliminary results concerning shrub ecotypes can be made, it was decided in the early stage of this study to establish a variety of shrub species. Detailed measurements and analyses then can be made at any time after establishment and adequate maturation. Some measurements of phenology and growth, however, will be made as soon as possible on two or three species as described below. The species selected for study represent a variety of habitats, and varying tolerance widths. All are important constituents in one or more shrub communities of the region. They are:

Amelanchier alnifolia	Cercocarpus montanus
Artemisia tridentata	Symphoricarpos oreophilus
Atriplex canescens	Purshia tridentata
Ceratoides (Eurotia) lanata	

Population representatives will be collected for two geographic scales: 1) the broad region of western Colorado and contiguous areas in other states; and 2) within a local landscape unit of the Piceance Basin. The last will be closely related to the phytosociological gradient study of the landscape from which the different sample populations come.

For each species at least five locations from the wide geographic range will be used. For each of these collection sites, eight different individuals will be represented. Replications for one of the species will be used to test for garden homogeneity. Investigation of ecotypes along a local environmental gradient in the Piceance Basin will initially involve one or two species, which will be collected from 12-15 sites on a gradient determined in our phytosociological studies.

Correlations of different ecotypes with differences in their native environments is essential to understanding ecotypic variation. This is especially so if the correlations can be interpreted in terms of their biological (adaptive) advantages. For each population collection site environmental data on such factors as elevation, latitude, growing season length, slope direction, slope steepness, and soil characteristics will be obtained.

The following is our anticipated time table for the establishment of the shrub garden:

Spring/Summer 1977	collection of propagation material, rooting in mist
Mid-Summer 1977	rooted cuttings planted in pots and maintained in greenhouse and growth chambers
Fall 1977/ Early Spring 1978	potted plants established in main shrub garden; backup materials planted at Meeker
Summer 1978 and Continuing	measurements of phenology and growth

Depending on growth and survival, initial measurements can be taken during the summer of 1978. The first reliable and intensive measurements will be made in the following growing season. If the attempts to propagate Symphoricarpos oreophilus from dormant cuttings during winter 1977 are successful, some transplant establishment for the geographic study as early as the summer of

1977 is possible and measurements in the late summer of 1977 or spring of 1978 can be expected.

The specific measurements made on the garden material will depend in part on what will be learned in the meantime about each species' seasonal cycle and growth habits, and the measurements to be made will vary with the species. Measurements to indicate ecotypic differences in phenology, morphology, vigor and growth will be made and will include:

a. time of growth initiation
b. time of leaf expansion
c. cessation of stem growth
d. leaf fall
e. dormancy
f. leaf size
g. annual stem length growth
h. growth form

For plants which reach reproductive age, measurements will include:

a. time of flower bud expansion
b. anthesis
c. time of fruit ripening
d. seed and fruit production

Phytosociological Studies

The phytosociological studies are concerned with giving a quantitative description of the vegetation of the Piceance Basin with the potential to inform reclamation efforts and provide a context for interpreting any ecologic-genetic variation found in the projects' other plant materials investigations. The problem posed by the physiognomically diverse vegetation of the Piceance Basin to a sampling program which will allow intercommunity comparisons is formidable. Our approach to this involves essentially three different sampling procedures for each stand. The herbaceous layer is measured by area quadrats for frequency. The trees (including saplings and seedlings of tree species) are measured in larger area quadrats for density, basal area, and frequency. Shrubs, the predominant life form of the region, are measured for cover in three different strata.

Environmental measurements and estimates to be made in each stand will be limited to those which can be taken in any stand on any day. No permanent, long term equipment will be installed. The values to be recorded are: slope, exposure, elevation, slope position, parent material, soil depth, soil texture, soil structure (blocky vs. granular), soil color (dark, medium, light) and lime layer (depth). These basic measurements and estimates can be combined into various scalars for further analysis.

Our tests show that for a practiced two-man sampling team, a day may be required to adequately sample the most difficult types (tall shrublands), while up to four stands of low shrubland types may be sampled in a day.

This sampling regime will be implemented in the growing season of 1977. Data will be compiled and analysis begun in fall 1977. Standard methods of direct and indirect gradient analysis will be used to get preliminary models of the vegetation. This is the first task of articulating quantitatively the relations of the vegetation to the landscape and also to the ecotype and selection studies. The model may also reveal "gaps" in our data and thus help direct data collection for the next field season. In addition, maintenance of and addition to the project herbarium will be continued.

BUDGET
SUBPROJECT D(B)

	Year 2
1. SALARIES AND WAGES	
aa. Scientific Discipline Personnel	
*Co-Investigator, R. T. Ward 100% of time for 1½ months	$ 4,700
*Associate Investigator, R. L. Dix 100% of time for 1½ months	4,200
*Junior Research Associate 50% of time for 9 months; 100% of time for 3 months	7,425
Graduate Research Assistant 50% of time for 12 months	4,400
bb. Support Personnel	
*Secretary	850
Hourly Labor	5,000
cc. Fringe Benefits	
10.64% of *	1,827
Total salaries, wages and annuities	28,402
2. INDIRECT COSTS	
64% of salaries, wages and annuities	18,177
3. EQUIPMENT	
In excess of $1,000:	
Pop-up camping trailers (2)	3,000
Other equipment:	
Rototiller	350
4. SUPPLIES AND MATERIALS	
Plant collecting, drying and filing	500
Peat pots, perlite, growth chamber potting trays	500
Miscellaneous field and laboratory	1,000

5.	TRAVEL	
	To and from research sites	$ 4,000
	Scientific meetings	600
6.	PUBLICATIONS AND REPORTS	300
7.	TOTAL DIRECT COSTS	38,652
8.	TOTAL SUBPROJECT COSTS	56,829

SUBPROJECT E

TITLE: INTERACTION AMONG PLANT SPECIES, SOIL MATERIAL, CULTURAL PRACTICES, AND ENVIRONMENTAL PARAMETERS ON PLANT COMMUNITY ESTABLISHMENT AND RATE AND DIRECTION OF SECONDARY SUCCESSION.

PERSONNEL: Dr. C. Terwilliger, Jr., Professor
Mr. David A. Koehler, Research Associate
Mr. Douglas E. Johnson, Graduate Research Assistant

OBJECTIVES:

1) To determine the proper reseeding practices for potentially usable plant species and mixtures of plant species and their relationship to cultural practices and inputs.

2) To determine the rate and direction of plant community succession as influenced by: a) mixtures of species used in revegetation,
b) cultural practices, and
c) soil conditions

3) To develop information and guidelines for increasing the successful germination of important native plants.

CONTINUATION PROPOSAL

Revegetation Technique Plot

Beginning June 1, 1977, the revegetation technique plots will be sampled by non-consumptive quantitative methods to establish the emergence baseline of the various species seeded. Thereafter, the plots will be re-sampled at monthly intervals throughout the growing season to determine attrition and survival. Five 1/10 m "Daubenmire" quadrats will be situated in each of the sub-subplots by means of random coordinates (Payne, 1974; Daubenmire, 1959). Data recorded on each quadrat will include:

- number of plants of each species
- an estimation of cover by each species
- maximum height of each species

Subsequent reduction of this data will also yield:

- vigor (as evidenced by height indices)
- frequency
- density

Statistical analysis of field data will test the null hypothesis that fertilizer treatments, irrigation applications, and seeding techniques do not affect the emergence or survival of the species mixtures being tested. The hypothesis will be tested by subjecting the data to multivariate analyses of variance. Significant differences between and among treatments may then be detected by the application of F-tests and Tukey's "honestly significant difference" procedure (Sokal and Rohlf, 1969).

Successional Plots

Randomly placed, 1/4 m^2 plots (25 cm x 100 cm) will be located within the sub-subplots using random coordinates on a grid system. Seedling emergence data collected beginning June 1, 1977, will include plant number per unit area and mean maximum plant height. The sampling period beginning August 15, 1977, will concentrate on parameters concerned with seedling establishment; viable seedlings per unit area, mean maximum plant height, and estimated biomass per plant species. Species data will include those which are seeded as well as invader plants. Seedling height will be used as an index to plant vigor, and seedling number and biomass to compare treatments among and between groups. Significance will be tested statistically by analysis of variance procedures and Tukey's Multiple Range Test. Subsequent years data will include density, height and biomass measures.

Annual Disturbance Plot

These plots will be sampled by the same methods as the successional plots, in fact, will provide the control plots for future comparisons.

In the fall, another replicate of these plots will be constructed. The primary emphasis for these plots will be to establish moderately disturbed areas that have been altered in specific ways for definite periods. These plots will then be investigated for microbiological and secondary plant successional changes. Documentation of natural secondary succession should provide an interesting contrast to the artificially induced successional plots.

Revegetation of retorted shale

At the intensive study site two test plots will be constructed where studies can be carried out concerning plant and small animal succession and microbiological successional changes in plant communities overlying processed shale. Other studies to be enacted in the future could also utilize these plots.

The first of the successional plots will be constructed with the use of Paraho processed shale. Paraho processed shale was selected because it will be readily available and because it may be one of the major by-products of the oil shale retorting process. The second successional plot will be developed with the use of a mixture of Tosco II and Paraho processed shales. The Tosco II process may also be an important retorting method during commercial development. It has been stated in Rio Blanco Oil Shale Project's Detailed Development Plan for Oil Shale Tract C-a that their processing operation will involve both the Tosco II and Paraho methods.

Spent Shale Successional Plot (Paraho Retort Process)

Successional plots on processed shale will be used to evaluate the effect of retorted shale properties, depth, and disposition on the rate and direction of plant community succession. Species mixtures, cultural practices, and soil amendments will be tested for their ability to aid restoration of functional ecosystems on disposal sites for spent shale.

The experimental design for the successional plot will consist of three treatment variables applied in a split-split plot design (Figure E1). This basic design will be replicated three times. The sub-suplot size will be 9 x 18 meters. Main plots will consist of treatments that will simulate processed shale disposal piles presently proposed by industry and will also provide a realistic environment to approach important research questions (see Supplemental Request, February 7, 1977).

The various treatments will include:

1) processed shale without any surface covering
2) 30.5 cm soil over spent shale
3) 61 cm soil over spent shale
4) 91.5 cm soil over spent shale
5) 61 cm soil over 30.5 cm capillary barrier over spent shale
6) soil check with no spent shale

On all plots containing retorted shale, the shale will have a depth of two feet or more. The total retorted shale requirement is estimated to be 18,710 cu. meters.

Subplots on the successional plots will consist of three vegetation mixtures:

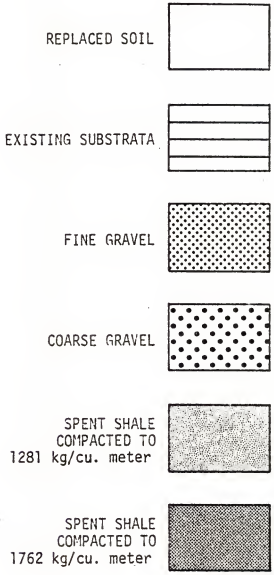
1) a native grass-forb mixture
2) an introduced grass forb mixture
3) a grass-forb-shrub mixture containing both native and introduced species

Sub-subplots will consist of three fertilizer treatments:

1) 0 kg/ha, 0 kg/ha
2) 56 kg/ha, 28kg/ha
3) 112 kg/ha, 56 kg/ha

The third fertilizer treatment will be the same as one treatment to be used on the Nitrogen-Phosphorus Balance Plots to provide an interconnecting link between

LEGEND


REPLACED SOIL
EXISTING SUBSTRATA
FINE GRAVEL
COARSE GRAVEL
SPENT SHALE
COMPACTED TO
1281 kg/cu. meter
SPENT SHALE
COMPACTED TO
1762 kg/cu. meter

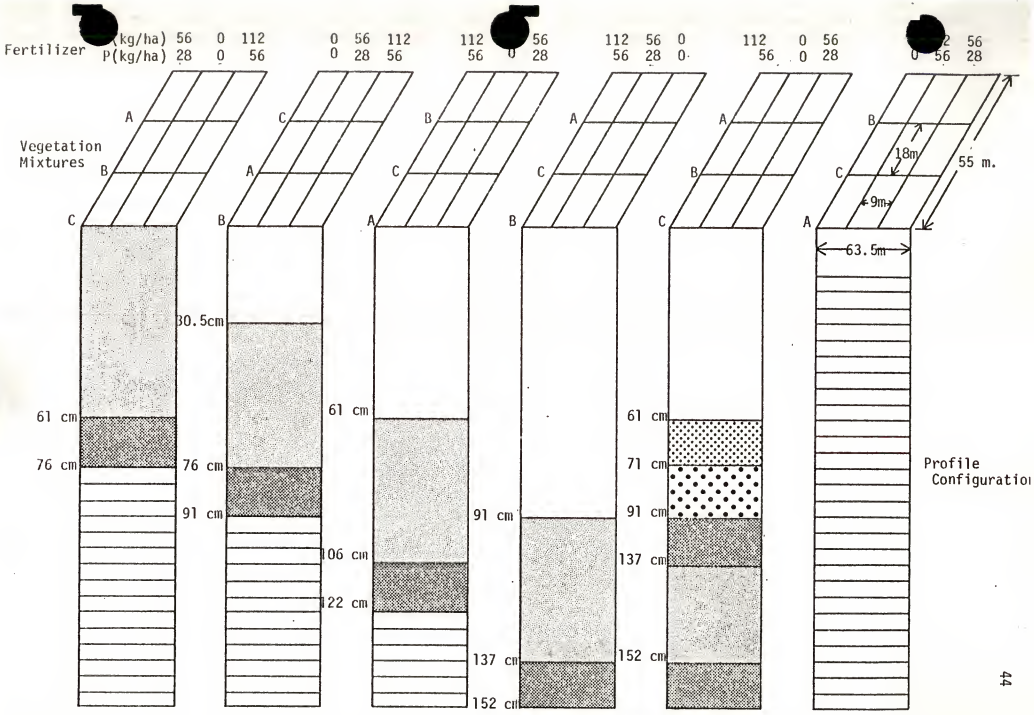


Figure E1. Processed Shale Successional Plot Using Paraho Retorted Shale (See Supplemental Request, Feb. 7, 1977)

the two plots. Nitrogen will be applied annually for five years while phosphorus will consist of only a single application the first year.

The retorted shale for the plot and the other plots requiring Paraho spent shale will be transported from the Anvil Points facility near Rifle to the Intensive Study Site, approximately 98 kilometers. Transport will be the most expensive aspect of plot construction.

Spent Shale Successional Plot (Tosco II and Paraho Spent Shale)

This test plot was not proposed in the Supplemental Proposal of March, 1976. However, because of the availability of Tosco II spent shale and because of the probability that more than one retorting process will be used, we are proposing an additional test plot to study long-term plant community succession on a mixture of two spent shales.

The profile configuration (Figure E2) for this test plot will be identical to the previously described succession plot. The main differences will be that the processed shale will consist of 65 percent Tosco II and 35 percent Paraho as is proposed in the disposal plan for the Rio Blanco Oil Shale Project's Tract C-a (Figure E2). The limited amount of Tosco II processed shale that is available dictates that the test plot will be minimal in size and only encompass approximately 0.12 hectares. Subplots will measure 6.7 x 9.8 meters. The total spent shale requirement is estimated to be 818 cu. meters. Of this, 531 cu. meters will be transported from the Colony operation in Parachute Creek. The remainder will be transported from Anvil Points. Correspondence with Colony personnel indicates their willingness to provide the Tosco II processed shale for this research effort.

Suplots on this succession plot will consist of one vegetation mixture and one fertilizer treatment that will link this plot to both the Nitrogen-Phosphorus Balance Plot and the original processed shale succession plot.

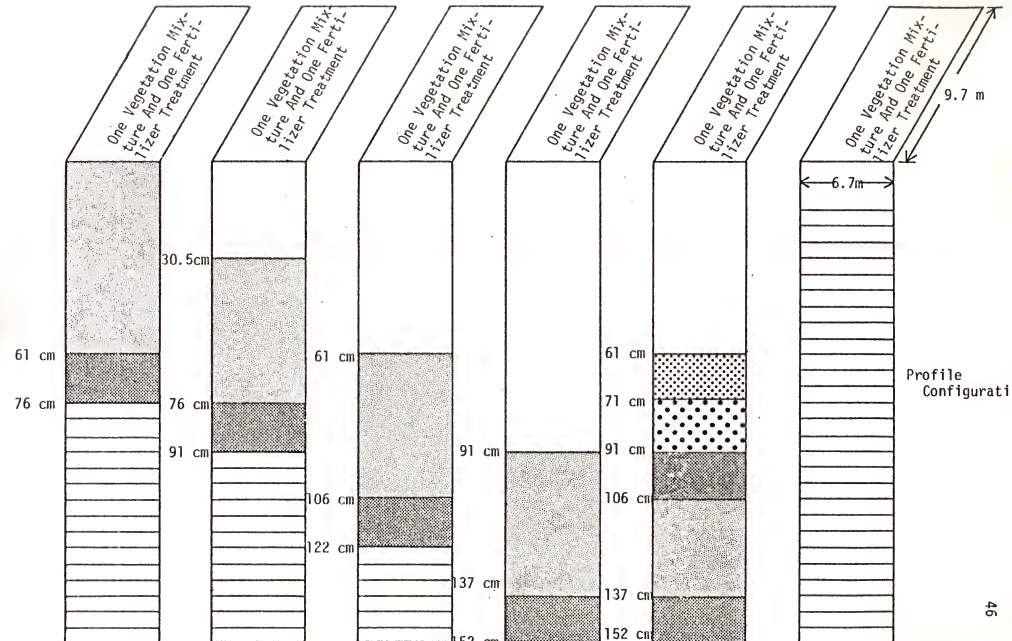


Figure E2. Processed Shale Successional Plot Using TOSCO II and Paraho Retorted Shale (See Supplemental Request, Feb. 7, 1977)

Germination and Establishment of Important Native Plants

The nature of most western reclamation sites is characterized by extreme environmental conditions (absence of a vegetative cover, limited moisture, inadequate organic matter, a harsh climate, and infertile soils). The expense of manipulating this planting environment (topsoiling, cultivation, irrigation, fertilization, intensive management, etc.) to agricultural standards is prohibitively expensive in terms of the potential agricultural value of the land. In order to avoid costly long-term inputs of management and natural resources, a viable alternative is to establish vigorous, self-sustaining ecosystems similar to native ecosystems. To accomplish this objective with any degree of predictability, however, certain gaps in current reclamation technology must be bridged.

The problems addressed here are concerned with gaps in information regarding germination qualities of several native plants. With increasing concern for extreme environments, such as are encountered during the reclamation of disturbed land, the importance of studying responses at both the upper and lower limits of a plant's tolerance becomes apparent. Such studies allow some prediction of a plant's potential adaptability in both competitive and non-competitive situations (Rorison, I. H. 1969).

Specific gaps in information emphasized by this research include: 1) lack of information on how germination requirements of native plants respond to the environmental characteristics of severely disturbed lands; 2) the need for more ecologically sensitive planting methodologies; and 3) the need for adequate guidelines for tailoring germination of important native plants to the planting environment. The purpose of the research outlined here is to develop specific information on germination requirements of several important native plants as well as the development of a methodology for determining more ecologically sensitive planting procedures. The research has been divided into several phases in order to outline a necessary sequence of events.

These phases are: 1) an intensive literature search, 2) selection of several important test plants, 3) determination of requirements for breaking dormancy, 4) determination of requirements for germination, and 5) a greenhouse demonstration of the range and optimum conditions for germination success in relation to important field conditions of daylength or aspect, soil moisture, soil texture, soil color and soil depth.

Phase I. Literature Search

The objective of Phase I is to conduct an intensive literature search on the techniques, methodologies and equipment for germination of native plants in the western United States. It has been divided into three sub-goals:

1. An annotated bibliography would be developed from an intensive library and government agency search as well as consultation with experts in the field.
2. A subject guide to the literature would be developed to provide accessibility to the bibliography.
3. A state of the art publication on the history of germination and establishment of native Western plants would be prepared.

Phase II. Selection of Test Species

Until recently, few non-economic plants have received attention concerning their cultivation. Some range plants, such as important forage grasses or those used in landscaping or horticulture (i.e., Western wheatgrass, Ponderosa pine, Colorado columbine) have been worked on extensively. Plants which are ecologically important to the shrub-dominated plant communities found in northwestern Colorado have received little attention until recently with the increased interest in drought adapted plants (i.e., Four-wing saltbush, Big sagebrush, Black greasewood, etc.). The majority of native plants which show a wide ecological amplitude, exhibit aggressive growth habits and are adapted to northwestern Colorado still have largely unknown cultivation requirements.

The plants that will be selected for this study will be based on the literature search in Phase I, two to three plants from the grass, forb and shrub categories will be selected as test plants. Criteria used in selection of these plants will be their importance for use in reclamation, availability of planting materials, adequacy of existing information, and results of present seedings at the Intensive Study Site.

Phase III. Dormancy Requirements

Seeds of most plants are unable to germinate while they are enclosed within the fruit attached to the parent plant, or for a period of time after fruit ripening and seed dispersal. Seeds whose germination is prevented by their own internal mechanisms are said to be dormant. If the seed is capable of immediate germination when subjected to proper environmental conditions, the seed is said to be quiescent or nondormant. The distinction between dormant and quiescent seed is that, in the first, germination control is due to mechanisms internal to the seed, and in the second, to environmental factors external to the seeds. Three conditions must be fulfilled before germination will begin: a) the seed must be viable, b) internal conditions of the seed must be favorable for germination, and c) the seed must be subjected to the appropriate environmental conditions.

Tests to be performed during this phase of the research are adapted from Hartmann and Kester (1975) and include:

1. Viability Test - Percentage of live seed will be determined from the tetrazolium test. Tetrazolium tests would be conducted by the Colorado Seed Laboratory on the campus of Colorado State University.
2. A series of germination tests with pregermination treatments will be conducted to determine the specific type of seed dormancy of each test plant.

Phase IV. Laboratory Germination Requirements

Both Phases IV and V can begin once pre-germination treatments are known. Both phases deal with the ranges and optimum germination conditions of the test plants involved. Phase IV is concerned with the measurement of each factor regulating germination in the laboratory. Phase V is concerned with the response of germination requirements to simulated field conditions in the greenhouse.

Using standardized seed germinators and techniques, adapted from Hartman and Kester (1975), and the Association of Official Seed Analysts (1970), a series of tests will be conducted to determine temperature, moisture and light requirements for optimum germination.

a. Temperature Requirements

Temperature is probably the single most important environmental factor that regulates germination. Different plants not only have upper and lower temperature limits for germination, but may also respond to specific seasonal or diurnal fluctuations. The overall temperature requirements tend to reflect the environment of the plant's native habitat.

Three temperatures (minimum, optimum, and maximum) will be determined for each species. This will be determined at both a constant temperature and at fluctuating diurnal temperatures of a 10^0 C difference. Each species will be germinated at the following temperatures:

1. Constant -- in degrees Centigrade: 10, 15, 20, 25, 30
2. Fluctuating -- 12 hours minimum and 12 hours maximum in degrees Centigrade: 10-20, 15-25, 20-30, 25-35.

b. Light Requirement

Light sensitivity is now recognized as a major ecological factor in adaptation of plant species. Light-sensitive seeds are often small and germination is favored by placement near the soil surface where the seedlings can emerge

quickly and begin photosynthesis. Seedling survival is reduced or eliminated by planting at too great a depth or in close proximity to other plants where there would be an intense competition for light.

By contrast, plants with light-inhibited seeds tend to be found in dry desert environments where seedling survival would be enhanced if the seeds germinated at somewhat greater soil depths where there is less heat and more moisture.

The light requirement of many seeds tends to disappear with dry storage and can often be overcome by chilling, alternating temperatures, or chemical treatments. In the proposed research, all species will be germinated in each temperature test in both the light and dark. The light period will be of 12 hours duration each 24 hour period in both the constant and fluctuating temperatures. Moisture conditions will be maintained at an optimum level during all of the light and temperature tests.

c. Moisture Requirements

The rate of water absorption for germinating seeds has three phases: a) an initial rapid uptake due to imbibition, b) a slow intermediate period, and c) a second increase in uptake as the radical emerges and the seedling develops. Because of their colloidal nature, dry seeds have great absorptive power which varies as a function of the nature of the seed, the permeability of the seed covering, the availability of water, and the temperature. Higher temperatures increase water uptake.

The moisture supplied to the germinating seed may affect both the germination percentage and the germination rate. Germination percentage tends to be equal over most of the range of available moisture from field capacity to permanent wilting percentage. Differences among species become evident as the moisture content of the soil approaches dryness (Hartmann and Kester, 1975).

Adequate moisture will be provided in all germination tests until the temperature and light requirements are determined. At this time, the lower limit of moisture will be determined to achieve germination at optimum temperature and lighting conditions. Each species will be tested for the lowest level of moisture it will germinate at with five different moisture levels.

d. Germination Time

All germination tests will be recorded every 5 days to determine the germination percentage at each 5-day interval up to 30 days.

Phase V. Greenhouse Simulation of Field Conditions to Develop Guidelines for Field Plantings

In order to develop guidelines for field planting of native plants, it is necessary to know how the germination requirements of particular plants respond to the basic planting environment variables of soil texture, color, moisture, temperature, planting depth, and day length. All of these factors interact with each other and modify the overall planting environment to either enhance or suppress seed germination. For example, it has been found that where soil conditions are not ideal, the germination resistance (dormancy requirements) of the resulting seed crop is high; and vice versa, better growing conditions lead to lower germination resistance (Gordon, 1973).

In most reclamation planting, it is neither economically or ecologically desirable to try to develop a controlled germination environment over large areas to ensure germination success. By taking advantage of microhabitats created by topographic variations (slopes, slope facings, landforms) and soil types, planting techniques can be tailored to the germination requirements of the plant and its planting environment.

The major factors influencing seed germination are temperature, moisture, and light. Temperature is modified by soil color, day length, soil moisture, and planting depth. Soil moisture is modified by soil temperature, soil

texture, planting depth and precipitation. Lighting is modified by day length, soil texture, soil color, aspect, and planting depth. Because few of these variables can be kept constant in the field and each influences each other, guidelines which are developed from combination of factors showing the range of germination response to simulated field conditions will have greater applicability to actual field conditions.

In this phase of the research, potted samples in a greenhouse with temperature and lighting controls will be utilized to develop the planting guidelines. Factors to be measured and correlated are:

1. Soil Color - 3 treatments (light, medium, dark). A thin layer of colored sand would be spread over each pot to standardize the soil colors.
2. Soil Texture - 5 treatments (sandy, sandy loam, loam, clay loam, and clay).
3. Soil Moisture - 3 treatments (dry, moist, wet). The soil in the pots would be brought to field capacity once at the beginning for dry; again ten days after the first for moist; and again at 20 days and at 30 days for wet. Percent soil moisture will be measured per treatment at 15, 25, and 35 days.
4. Planting Depth - 5 treatments (0.5 cm, 1.0 cm, 2.0 cm, 4.0 cm, 6.0 cm.)
5. Day Length - 3 treatments (14 hours, 12 hours, 10 hours). Lighting will be controlled for minimal levels with supplemental artificial lights, photocell switch and timer.

A planting guideline chart will be developed for each species from the results of the experiment. The following is used for illustration. For each combination of soil texture and soil color, the optimum germination results will be listed giving: moisture regime, planting depth, percent germination, and germination time.

PLANTING GUIDELINES SPECIES X

SOIL TEXTURE	SOIL COLOR		
	Light	Medium	Dark
Clay	Long Day Moisture Planting Depth Germination % Germination Time Medium Day Moisture Planting Depth Germination % Germination Time Short Day Moisture Planting Depth Germination % Germination Time		
Clay Loam			
Loam			

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BUDGET
SUBPROJECT E

		Year 2
1.	SALARIES AND WAGES	
	aa. Scientific Discipline Personnel	
	*Co-investigator, Charles Terwilliger, Jr. 100% of time for 1½ months	$ 3,675
	*Junior Research Associate, David Koehler, 100% of time for 12 months @ $990/month	11,880
	*Junior Research Associate 100% of time for 12 months @ $990/month	11,880
	2 Graduate Research Assistants 50% of time for 12 months	8,800
	bb. Support Personnel	
	Hourly Labor	3,000
	cc. Fringe Benefits	
	Public Employees Retirement Association, 10.64% of *	2,919
	Total salaries, wages and annuities	42,154
2.	INDIRECT COSTS	
	64% of salaries, wages, and annuities	26,979
3.	EQUIPMENT	
	Soil test equipment	1,000
	Meterological equipment	1,500
4.	SUPPLIES AND MATERIALS	
	Plant markers and stakes	500
	Earth moving tools	300
	Tool boxes	250
	Storage cabinets (field)	500
	Miscellaneous	1,000
5.	PUBLICATIONS AND REPORTS	1,500
6.	TRAVEL	
	To and from research site	2,500
	Scientific Meetings	500

7.	OTHER DIRECT COSTS	
	Laboratory soils analyses	$ 1,500
	Laboratory seed analyses	400
	Computer services	500
8.	TOTAL DIRECT COSTS	54,104
9.	TOTAL PROJECT COSTS	81,083

SUBPROJECT F

TITLE: THE IMPORTANCE OF MYCORRHIZAL FUNGI IN SALVAGING AND STABILIZING SPENT OIL SHALE WITH NATIVE VEGETATION.

PERSONNEL: Dr. F. Brent Reeves, Jr., Associate Professor
Mr. Tom Moorman, Graduate Research Assistant
Miss Jean Kiel, Graduate Research Assistant

OBJECTIVES

The objectives of this subproject are to determine 1) the absolute numbers of mycorrhizal spores in disturbed versus undisturbed soil, 2) the various types of mycorrhizal fungi present in undisturbed sites, and 3) the population dynamics of mycorrhizal fungi.

CONTINUATION PROPOSAL

Because all the samples of the important plants of the native ecosystem in the oil shale region are mycorrhizal, we are reasonably convinced that the lack of mycorrhizal spores is very important in determining the success of rehabilitation. Our goal now is to determine the absolute numbers of mycorrhizal spores in the disturbed vs. undisturbed soils, i.e., numbers of spores per gram of soil, and most importantly, the viability of the spores. Currently we are developing accurate methods for sieving the spores from the disturbed and undisturbed soil and checking their germination. Numbers of spores mean nothing if they are not capable of establishing mycorrhizal relationships with the native vegetation. The results of this aspect of the study hopefully will strengthen our hypothesis.

Another very important aspect of this work is determining the various types (species) of mycorrhizal fungi present in undisturbed sites or native vegetation. If more than one species of mycorrhizal fungi is present in an undisturbed site, it is essential that when that site is disturbed the disturbed site is seeded with higher plants which will maintain the fungi so that rapid recovery of the ecosystem can be achieved. This goal can be

attained by the continued survey of the native vegetation for the occurrence of mycorrhizae and the species of mycorrhizal fungi present in both the roots and the soil (some mycorrhizal fungi do not produce spores).

From the soil collected at the dump site, we are extracting mycorrhizal spores and establishing pot cultures so that artificial inoculation on native plants for future study can be made. Our goal is to establish pot cultures of the major species of mycorrhizal fungi so we can make better comparative studies as to the relative effectiveness of each species of mycorrhizal fungi on each selected species of native host. The data for determining the major species of fungi will be generated from the sieving experiments. From these pot cultures we intend to grow the native hosts (with and without mycorrhizae) under various conditions including a medium of disturbed soil over processed shale.

We believe that an extremely important aspect of this work is a study of the population dynamics of the mycorrhizal fungi. If data indicate that the number of viable spores is quite variable with the seasons, then this information may indicate when the best time for soil disturbance and/or storage occurs--that is, disturbance would best occur during a period of maximum number of viable spores so that the potential for the reestablishment of mycorrhizae is increased. How the details of this aspect of the research will proceed will depend on the rate and accuracy of the information gained in the preceeding work.

Our preliminary results with the bioassay of the soil were so good that this experiment is currently being repeated using total raw soil (100% soil, disturbed and undisturbed) as well as the diluted soil as in the initial experiment. If the bioassay remains successful, then this may prove to be an extremely useful method of quickly and cheaply estimating the mycorrhizal rehabilitation potential of a given disturbed soil.

Finally, we must correlate our work with the information generated at the Intensive Study Site. We have collected soil (both ripped and mixed) at this site to analyze for numbers of mycorrhizal spores. This information will be correlated with that provided by Dr. Klein in his studies of other microorganisms. We are particularly interested in checking the relative success of reseeded vegetation on the test plots and their degree of mycorrhizal infection. It is our intent to monitor these seedlings as they develop. Also we intend to survey the invasive vegetation which volunteers on the annual disturbance plots for mycorrhizal development. This information can provide us baseline data for potentially predicting the role and innoculum potential of mycorrhizal spores under field conditions.

The current strategy for reclamation includes possible introductions of native or exotic legumes able to fix nitrogen. Several recent investigations have demonstrated that certain but not all legumes grow better and have increased nodulation when they are mycorrhizal. Since the legumes represent a potential natural mechanism to reduce nitrogen fertilizer requirements we must examine those suggested for use for their response to mycorrhizal infections. Dr. Cuany currently has several legumes under cultivation as potential elements in the revegetation efforts. We will cooperate with Dr. Cuany in using his materials for these studies.

Our ultimate aim is to determine the relative importance of mycorrhizae in successful rehabilitation techniques in our semi-arid environment. Because this area of research has never been investigated, our ideas must remain somewhat flexible as data is gathered and analyzed. If, as we suspect, the numbers of mycorrhizal fungi are significantly reduced with disturbance then we must devise methods of increasing the numbers of those essential species of fungi if we expect a natural ecosystem to become established and be maintained. Currently we have a total void in the technology for producing large numbers of mycorrhizal fungi. Hopefully successful directions towards

applied technology can be gained through our collaborative efforts in defining the real problems associated with rehabilitation in semi-arid environments.

BUDGET
SUBPROJECT F

	Year 2
1. SALARIES AND WAGES	
aa. Scientific Discipline Personnel	
*Co-Investigator, F. B. Reeves 100% of time for 1½ months	$ 3,360
Graduate research assistants, Tom Moorman and Jean Kiel, 50% of time for 12 months	8,800
bb. Support Personnel	
Hourly Labor	3,000
cc. Fringe Benefits	
Public Employees Retirement Association, 10.64% of *	358
Total Salaries, Wages and Annuities	15,518
2. INDIRECT COSTS	
64% of Salaries, Wages, and Annuities	9,932
3. SUPPLIES AND MATERIALS	
Greenhouse supplies	500
Reagents and chemicals	400
Glassware, slides, coverglasses	400
Microbiological media	400
Photosupplies	300
Reference materials, Xerox, etc.	300
4. EQUIPMENT	
In excess of $1,000: Growth Chamber, Sherer 3610	3,500
Other equipment:	
Colony counter	500
Copy camera back	400
Repair and replacement	400
5. PUBLICATION AND REPORTS	400
6. TRAVEL	
Colorado--Intensive site and subsistence	2,500
Scientific Meetings	1,000

7.	CONSULTANT SERVICES	
	Dr. Martha Christensen, Univ. of Wyoming	$ 3,000
8.	TOTAL DIRECT COSTS	29,518
9.	TOTAL PROJECT COSTS	39,450

BUDGET JUSTIFICATIONS

1. Salaries and Wages

Both Moorman and Kiel are currently working on this project full time for their degrees. They now have experience with mycorrhizae and their work is progressing.

Wagner, an undergraduate, began work last June, 1976, and has been a major contributor to the project. His knowledge of the higher plants has been invaluable to the mycorrhizae studies.

5. Equipment

Growth chamber. To establish and maintain pot cultures of selected mycorrhizal fungi we need a plant growth area which is free from potential contamination. An isolated greenhouse would be preferable but this is not possible. The alternative is a plant growth chamber.

Other equipment. A copy camera back for our copy apparatus to provide slides for scientific presentations and other materials for reports and publications is requested. The colony counter will be used in estimating numbers of saprobic fungi as correlated with viable mycorrhizal propagules.

8. Consultant Services

Consistent with ERDA's suggestion on the initial proposal, the mycorrhizal and field expertise of Dr. Martha Christensen will be employed again.

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REHABILITATION POTENTIAL AND PRACTICES OF COLORADO OIL SHALE LANDS

Progress Report for Period
June 1, 1976 - May 31, 1977

Phillip L. Sims
Principal Investigator

Colorado State University
Fort Collins, Colorado 80523

February 1977

Prepared for

THE U.S. ENERGY RESEARCH AND DEVELOPMENT ADMINISTRATION
UNDER CONTRACT NO. E(11-1)-4018

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ABSTRACT

Substantial progress has been made towards implementing all of the prescribed studies and satisfying the stated objectives since the Oil Shale Rehabilitation Project was actively initiated in June 1976. Concurrent with implementation, research objectives were substantively defined and supplemented without distracting or departing from the original purpose. Current studies are designed to fill voids in the present status of knowledge regarding lands disturbed by an impending oil shale industry in Colorado. The efforts of all contributing investigators have therefore been integrated and directed toward the goal of developing methodologies requisite for restoring diverse and complex ecosystems which will require only a minimal amount of maintenance or input of scarce resources.

An intensive study site southeast of Oil Shale Tract C-a has been obtained through a Cooperative Agreement with the Bureau of Land Management. Following this agreement, most subprojects were initiated at the intensive site. Additional programs will be implemented as spent shale becomes available this summer. Studies conducted principally in the laboratory and greenhouse, such as the microbiological and plant genetic studies, have achieved significant results. Other studies that require more intensive field application will not generate data until next field season.

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INTRODUCTION

Research conducted by each investigator during the 1976 funding period resulted in significant contributions to the overall goal of the project. This report describes these accomplishments along with significant results that have been obtained. The following paragraphs give a brief summarization of the progress to date for each subproject.

A. Resource Management Unit Handbook

Existing information has been integrated into descriptive characterizations of ecosystems occurring in the Piceance Basin. Sources of this information included vegetative community maps (Cook, 1974), Soil Conservation Service (SCS) soil resource inventories, and vegetation-soil studies, plus available climatic, geological, geomorphological, and hydrological information. Ecosystem characterizations thus derived have been incorporated into a Handbook which also describes the risk factors associated with land disturbances. The Handbook contains a dichotomous key to the resource management units, designed to facilitate unit identification by laymen or workers unversed in the regional ecology. The first draft of the manuscript has been completed at this date. Publication of the Handbook will be completed by June 1, 1977.

B. Long-Term Fertility Requirements

Field studies have not been initiated for this subproject due to the unavailability of processed shale from the Paraho project. However, in anticipation of retorted shale availability this summer, preparatory

investigations have been completed. The activities this year involved the study of pertinent literature and developing a plan and strategy for the plot work that will be set up as soon as the retorted shale is available. Arrangements for purchasing and transporting the wood materials, sewage sludge, and chemical fertilizer have been pursued so that the plots can be established early in the summer of 1977. Equipment for N and P analyses is being ordered and/or prepared and procedures have been investigated so that time will not be lost when this study gets underway.

C. Role of Soil Microorganisms

Major efforts were directed the first year towards the development of techniques to be used to sample the intensive study site. A total of 224 soil samples were taken during summer and fall 1976 from six revegetation plots in the general region. Microorganism populations were enumerated for each sample, nitrification activity and non-symbiotic nitrogen fixation rates were measured, and methods for determination of fungal versus bacterial contributions to carbon flow processes were evaluated. In January 1977, 62 soil samples were taken from the intensive study site to provide a baseline inventory of microbial populations. These are in the process of being analyzed at the present time. Studies in progress will evaluate rehabilitation techniques for their ability to provide maximum microbial nutrient cycling and energy flow.

D(a). Development of Improved Strains of Grasses, Legumes, and Forbs through Selective Breeding

Plant materials selection and improvement has advanced during 1976 through seed collection, planting of breeding nurseries, and two types of

field trials. Emphasis has been centered on the grass species previously proposed (western wheatgrass and Indian ricegrass) and likewise on legume species (lupine, Utah sweetvetch, and cicer milkvetch). Many germplasm sources have been collected, and those with sufficient seed have been planted as spaced plants in breeding nurseries, as seeded rows in two field trials in the Piceance Basin, and in seed production trials in western Colorado. Seed harvested from older nurseries has been prepared for controlled-stress germination tests. The first evaluations of field-site performance from 1976 plantings will begin in spring 1977. These evaluations are to explore genetic differences which will lead to ecotype selection and breeding of desirable characteristics into improved strains for rehabilitation uses.

D(b). Suitability of Native Shrubs and Forbs for Shrubland Restoration

The presence and extent of ecotypic differentiation of selected shrub species and the nature of vegetational variation on the landscape are being studied in relation to implications for reclamation. Adaptation by local populations to environmental gradients is indicated by natural variation in genetically determined ecological traits and natural variation in phytosociological structure. An understory of the evolutionarily derived correlations of genetic variation with environmental and phytosociological variation will aid in matching genetic material to the environmental situtations under reclamation. The presence, extent, and nature of the genetic variation is being investigated by propagating plant materials from different sources in common gardens. The ecological significance of any variation found will be examined by relating the ecotypic variation to gradients of vegetation structure and the physical

environment. During the first field season, various phytosociological and genecological methods were developed to measure these various variations and gradients.

E. Interaction among Plant Species, Soil Material, Cultural Practices, and Environmental Parameters on Plant Community Establishment, Rate and Direction of Secondary Succession

Three plots were constructed, reseeded, and treated in the fall of 1976 to accomodate the proposed revegetation research. The Successional Test Plot contains 108 9x18 m subplots, with buffer zones between. Treatments applied were two mulch treatments, three fertilizer application levels, and six species mixtures. Each combination was replicated three times. The Revegetation Technique Plot contains six subplots, each measuring 17x92.5 m. Each subplot encloses 24 sub-subplots measuring 6x8 m and separated by buffer zones. Three of the subplots will be irrigated, three will not. Other levels of treatment are: fertilized vs. non-fertilized, three species mixtures, and four seeding techniques using various methods, depths, and rates. The Annual Disturbance Plot consists of 6x8 m subplots subjected to four intensities of disturbance. Each treatment was replicated twice.

F. Importance of Mycorrhizal Fungi

The hypothesis tested was that delays in reclamation procedures designed to create natural ecosystems on disturbed, semi-arid lands are due, in part, to a lack of essential mycorrhizal fungi in the soil. The initial research involved a comparison of a severely disturbed area adjacent to an undisturbed ecosystem similar to the proposed processed shale dump site. Results of this comparison revealed that 100% of the invasive plants (all the plants on the disturbed site) were non-mycorrhizal

whereas in the natural undisturbed ecosystem 86% of the plants were mycorrhizal.

Using corn as an indicator plant for mycorrhizal infection, a bioassay of the disturbed vs. undisturbed soil for potential mycorrhizal infection revealed that 60-90 days were required for mycorrhizal formation in disturbed soil but only 30 days were required for the undisturbed soil. Preliminary studies using saprobic fungi as indicators show that the number of fungal propagules are considerably reduced in disturbed soil. Further research designed to corroborate these data is planned and preparation for laboratory and field trials of mycorrhizal vs. non-mycorrhizal plants is being made.

The overall project objective is to develop detailed guidelines for reclamation of disturbed lands in the oil shale region. Specifically, we are seeking ways to initiate reestablishment of complex and diverse plant communities with minimum use of scarce resources. Currently, field research has been initiated on non-retorted shale plots that will investigate the relationships between types of vegetation and soil disturbances and microbial processes. During the coming year research results should provide insight into the relationship of re-invasion of plant species and soil microbial population dynamics and activity. Similarly, as plants emerge on the revegetation techniques study area some interesting soil treatment:plant materials:microbial relationship interactions should be apparent. Hopefully, the interrelationships between the subprojects will make important contributions to improved guidelines for rehabilitation of disturbed oil shale lands. In the coming years the interrelationships will be investigated on soil/retorted shale plots to elucidate guidelines useful for processed shale disposal areas.

INTENSIVE STUDY SITE

SITE SELECTION

In June, 1976, the principal investigator and co-investigators met with BLM officials from the Meeker Area Office and, in the course of a field reconnaissance, selected four possible locations for the intensive study site. The alternative sites were all situated between Ryan School and 84 Ranch, south of Tract C-a. Each had soils deep enough to accomodate the proposed retorted shale plots, according to a Soil Conservation Service soil survey completed in 1975. The following four locations were considered.

1. N½, SW¼ of S 4, T2S, R98W--north of Cascade Pipeline.
2. SW¼, SW¼ of S 33, T1S, R98W and E½, SE¼ of S 32, T1S, R98W--west side of road, half-way from jeep trail to 84 Ranch HQ.
3. NE¼, NW¼ of S 33, T1S, R98W and SW¼, NE¼.
4. NE¼, SW¼ of S 33, T1S, R98W and SW¼, NE¼--east of road and north of Division of Wildlife exclosure.

Final site selection occurred in early July. Basic criteria which were considered included: soil depth, access, size and shape of each area, aesthetics, and distance to water and electricity. Site #1 was chosen as the most suitable location. It is accessible from two sides--the main C-a Tract headquarters road on the east and the "Pipeline Road" on the south. The area is large enough to easily accomodate a 20 hectare study area in a variety of configurations. A power line extends up

Stake Springs Gulch, 2.4 kilometers north. Water is also available in Stake Springs Gulch, at 84 Ranch.

Physically, the site forms a semicircular basin, with a generally northern or northeastern exposure. The topography is slightly to moderately undulating. Erosion, though severe in spots, is not as pervasive as on the alternative sites. Soils are clay loams, loamy sands, or sandy clay loams and are generally deep as evidenced in the gullies which traverse the site. These are up to 1 or 2 meters deep and exhibit a suitable growth medium to that depth. The vegetation is the most profuse and diverse of any of the alternative sites. Sagebrush is relatively tall and dense; the interstices between shrubs have good ground cover with desirable grasses dominating the understory. Young pinyon-juniper, though widely scattered, has invaded the area.

A survey of the topographic configuration and boundary of the study area was made by project personnel (Appendix I, Figure 1). The area was located by reference to the brass cap marker at the corner of S 4, 5/8, R98W, T2S. As the boundary was circumscribed, direction of sight and backsight, distance, topographic arc, and elevational differences were recorded. Elevation differences were also measured and recorded on four transects, interior to the tract, at 4-chain intervals.

A formal survey was conducted in late October, 1976, by a registered professional land surveyor. The 20 hectares which was selected, surveyed and fenced is a parcel of land lying in the W½ of Section 4, T2S, R98W of the 6th P.M., County of Rio Blanco, State of Colorado. The approximate location of the site is shown in Appendix I, Figure 1.

BASELINE INVENTORY OF THE SITE

Vegetation

Two basic plant communities occupy the intensive study site. In July and August, 1976, these were sampled extensively to provide baseline information and quantitative data. A total of less than 60 species was encountered on the site, owing in part to the lateness of the sampling season. Many spring forbs had already disappeared from the composition of the local communities. Also, a dry spring affected composition by inhibiting the germination and growth of forb species which would ordinarily have occurred in local populations. A list of species encountered on the intensive study site is shown in Appendix I, Table 1.

Line intercept transects and m^2 quadrats were sampled in each of the site's principal plant communities--sagebrush and pinyon-juniper. These studies were implemented to obtain measurements of tree and shrub canopy intercept, relative cover by all indigenous plant species and frequency of occurrence by those species. Ten 30 m transects were sampled in each of the two major communities. Five m^2 quadrats were sampled along each transect.

"Daubenmire plots" (1/10 m quadrats) were utilized to estimate biomass of shrub, forb, and grass species encountered. Every fifth plot was clipped and weighed by species to provide an ongoing calibration of estimates. Clipped samples of "green herbage" were also obtained for later drying to provide "wet" to "dry" weight conversion ratios. A total of 200 quadrats was sampled in the more expansive sagebrush community, while only 100 quadrats were sampled in the pinyon-juniper community.

(A). In the Pinyon-Juniper Community, the most abundant grasses were slender wheatgrass (*Agropyron trachycaulum*), Indian ricegrass (*Oryzopsis hymenoides*), needleandthread (*Stipa comata*), and prairie junegrass (*Koeleria cristata*), occurring in 52%, 48%, 44%, and 24% of the subplots, respectively (Appendix I, Table 2). Ground cover contributed by each of these species was as follows: slender wheatgrass--1.89%, Indian ricegrass--0.39%, needleandthread--1.51%, and prairie junegrass--0.26% (Appendix I, Table 3). Biomass estimates for these species were as follows: slender wheatgrass--30.3 kg/ha (oven-dry weight), Indian ricegrass--12.1 kg/ha, needleandthread--51.8 kg/ha, and prairie junegrass--11.9 kg/ha (Appendix I, Table 4).

The most frequently occurring forb species in this community were miner's candle (*Cryptantha sericea*)--64% frequency, Hood's phlox (*Phlox hoodii*)--44%, bullhead gilia (*Ipomopsis congesta*)--40%, lobeleaf groundsel (*Senecio multilobatus*)--38%, and Nuttall goldenweed (*Haplopappus nuttallii*)--22% (Appendix I, Table 2). Miner's candle contributed 0.65% ground cover, Hood's phlox 0.82% ground cover, and longleaf phlox(*Phlox longiloba*) 0.17% ground cover (Appendix II, Table 3). Of the forbs yielding the largest biomass, miner's candle averaged 24.0 kg/ha, stemless goldenweed (*Haplopappus acaulis*) 16.5 kg/ha, and Nuttall goldenweed 10.6 kg/ha (Appendix I, Table 4).

Big sagebrush (*Artemisia tridentata*) with 44% frequency, and broom snakeweed (*Gutierrezia (Xanthocephalum) sarothrae*), with 26% frequency, were the most abundant shrubs (Appendix I, Table 2). Big sagebrush also exhibited 10.02% ground cover (Appendix I, Table 3). Big sagebrush was also the most productive species in this community, yielding 111.8 kg/ha

of oven-dried biomass; prickly pear (*Opuntia polycantha*) produced 32.1 kg/ha (Appendix I, Table 4).

(B). In the Sagebrush community, needleandthread with 50% frequency; Indian ricegrass, 47%; Sandberg bluegrass (*Poa secunda*), 35%; western wheatgrass (*Agropyron smithii*), 32%; slender wheatgrass, 31%; and bottlebrush squirreltail (*Sitanion hystrix*), 29% are the most abundant grasses (Appendix I, Table 2). Those grass species providing the greatest ground cover include needleandthread, 1.65%; slender wheatgrass, 1.06%; Indian ricegrass, 0.50%; western wheatgrass, 0.36%; and bottlebrush squirreltail, 0.32% (Appendix I, Table 3). Western wheatgrass was the most productive grass, yielding 65.7 kg/ha, followed by needleandthread and Indian ricegrass, yielding 42.9 kg/ha and 25.0 kg/ha, respectively (Appendix I, Table 5).

Hood's phlox, 56%; miner's candle, 34%; and bullhead gilia, 21%, were the most frequently occurring forbs (Appendix I, Table 2). Hood's phlox had a ground cover of 1.30% and miner's candle had 0.35% ground cover (Appendix I, Table 3). Hood's phlox also produced more biomass than any other forb--34.0 kg/ha. Scarlet globemallow (*Sphaeralcea coccinea*) produced 5.2 kg/ha (Appendix I, Table 5).

Big sagebrush was present in 67% of the subplots. Broom snakeweed was present in 18% (Appendix I, Table 2). Ground cover on the quadrats by big sagebrush averaged 15.77% (Appendix I, Table 3). This species also produced more biomass than all other species combined--277.1 kg/ha. Prickly pear produced 54.8 kg/ha (Appendix I, Table 4).

(C). In a study of transect intercept by shrub and tree canopy, the sagebrush community indicated an intercept, or cover, of 24.0%. Of this total, 23.3% was by big sagebrush (Appendix I, Table 6).

In the Pinyon-Juniper Community, cover by juniper (*Juniperus osteosperma*) equalled 19.7%, big sagebrush 13.3%, and pinyon (*Pinus edulis*) 6.6% (Appendix I, Table 6).

Soil Depth

A grid design was implemented for soil depth samples. A soil auger was used to facilitate the sampling. Soil depth samples were taken from each corner of the 48.5 hectare project area on which the intensive study site was to be located. Other samples were taken at 4-chain intervals in a north-south direction, at 8-chain intervals in an east-west direction. This design permitted the collection of a total of 50 soil depth samples.

Soil Testing and Analyses

Composite soil samples were taken from each of the six revegetation technique subplots. Four cores were drilled from the surface to consolidated material at approximately equidistant intervals down the middle of each subplot. The cores were placed in a bag and thoroughly mixed. Samples were then analyzed by the CSU Soil Testing Laboratory. Results are shown in Appendix I, Table 7.

CONTRACTUAL ARRANGEMENTS

BLM officials in the state, district, and area offices were kept apprised of the location, intent, and progress of the study. Efforts were extended to maintain contact with all involved agency personnel as preliminary studies and preparation progressed. In early September, pursuant to a BLM request, a Memorandum of Understanding was prepared and submitted for their approval. The Memo would authorize a cooperative agreement between CSU and BLM for use of the intensive study site.

Subsequently, the BLM requested that a Draft Environmental Analysis Report be prepared. This was prepared and submitted, and approval of the Memorandum of Understanding was extended in October.

Job descriptions were written for heavy equipment to construct the revegetation technique, successional, and annual disturbance plots and a short access road, to hydromulch experimental plots, and for fence construction around the site. These were submitted to CSU's Purchasing Department, along with a list of potential contractors. Bid Request Forms were mailed to interested bidders and firm bids were received during the second week of October.

Several seed dealers were contacted for their prices for the approximately 40 species to be seeded in the test plots. Sources for all species were located and seed was ordered by October 1 and received by November 15, 1976. During the actual seeding, it became apparent that a specialized seed drill would be necessary to accomplish the task within the restricted design and small area of the subplots. A tractor and drill were leased from a rancher near Meeker for that purpose.

A tour of the site was conducted in early December with area BLM officials. A general concurrence was expressed by the group that the conditions of the Memorandum of Understanding had been complied with and that obligatory conditions had been fulfilled.

SUBPROJECT A

TITLE: INTERPRETATION AND CHARACTERIZATION OF IMPORTANT NATURAL ECOSYSTEMS IN THE PICEANCE BASIN

PERSONNEL

Dr. Charles Terwilliger, Jr., Professor
Mr. James A. Tiedeman, Graduate Research Assistant

TIME EXPENDED BY CO-INVESTIGATOR FOR CURRENT TERM

Dr. Terwilliger--100% time for 1 month

OBJECTIVE

To prepare a guide to the ecosystems of the Piceance Basin describing the risk factors associated with disturbance of each ecosystem.

PROGRESS TO DATE

The first draft of the manuscript has been completed. Work on a revised Ecosystems Map of the Piceance Basin to accompany the manuscript is in progress. Review and publication of the Handbook will be completed by June 1, 1977.

The draft manuscript includes 200 pages plus 30 pages in the appendix. An annotated outline is given below.

I. Introduction

A general discussion of the approach and a justification of the work along with objectives and scope are included.

II. General Description of the Piceance Basin

This discussion includes location, general climate, geological material, soil, vegetation and land ownership.

III. Key to the Ecosystems and Resource Management Units in the Piceance Basin

A dichotomous key using vegetation, soil and land form characteristics was developed to guide a user of the handbook to an identification of a specific landscape.

IV. Guide to the Use of the Handbook for Characterization and Interpretation

This chapter includes a discussion and definition of terms, concepts, and abbreviations used in the chapter on interpretation.

V. Characterization and Interpretation of the Resource Management Units

Eighteen resource management units are discussed in detail in terms of the following major topics:

A. Description
B. Reclamation Considerations
   1. Hazards and Risks
   2. Revegetation Requirements and Alternatives
C. Vegetation Analysis
D. Soil Profile Description
E. Laboratory Chemical and Physical Analysis
F. Soil Interpretive Properties
G. Soil Use Limitations

As an example, the discussion and interpretations of one resource management unit is attached at the end of this report.

DESCRIPTION OF THE APPENDICES IN THE INTERPRETIVE CHARACTERIZATION HANDBOOK

A. Scientific and common names of plants in the Piceance Basin.

B. List of species expected to be most successful for revegetation within each resource management unit.

C. Monthly precipitation data for 1975 and 1976 at 11 locations in the Piceance Basin.

D. Average annual precipitation, minimum and maximum annual precipitation for the 95% confidence limits, and 80% chance annual precipitation based on precipitation records for the 1951-1970 period (Wymore, 1974).

E. Estimated irrigation water required (acre-ft.) for spring planted and full season irrigation of 10 acre revegetation areas on a horizontal surface (Wymore et al., 1974).

F. Resource management units listed in order of most favorable to least favorable for vegetation.

G. Resource management units listed in order of decreasing understory herbage productivity under natural conditions.

H. Literature review

Ecosystems
Vegetation
Domestic livestock and wildlife
Geomorphology
Geologic materials
Soils
Climate
Hydrology
Plant Succession

I. Methods used in the study.

RESOURCE MANAGEMENT UNIT

The following is a sample of the contents from Chapter 5 of the Interpretive Characterization Handbook and covers the Grassland Ecosystem.

GRASSLAND ECOSYSTEM

RMU-17--Bald ridges/shallow, gravelly loams

I. Description

This unit, characterized by high elevation dry ridge tops, occurs at the highest elevations in the Piceance Basin on north to east running ridges. Because of its ridgetop position and aspect toward the prevailing wind direction, a venticular wind effect occurs where the winds increase in velocity as they pass over these exposed ridges. Winds blow very strongly throughout the year with almost all the snow being blown off in winter. This prevents adequate soil moisture recharge so that these sites are excessively dry. Summer winds also have a desiccative

effect upon plants intensifying the drought conditions. Plants are also subjected to extremely low temperatures due to the lack of snow cover. The soil is not adequately protected by plant cover with over 30% bare ground exposed to wind erosion resulting in the development of a gravel pavement on the soil surface. The grassland ecosystem is the only type in the basin that occupies the windswept ridgetops at high elevations.

The unit has a vegetative cover of low shrubs, forbs, and grasses. The most common shrubs are fringed sagebrush (*Artemisia frigida*) and Douglas rabbitbrush. Dominant grasses are Indian ricegrass, needleandthread, and wheatgrass species. The characteristic forbs are mat penstemon (*Penstemon caespetosus*), spearleaf wildbuckwheat, and nuttall goldenweed.

Soils are less than 20 inches deep with more than 25% coarse fragments. The geological material is primarily shale of silt to fine sand sized particles. Elevations range from 7,500 to 8,500 feet with slopes from 0 to 30%. The mean annual precipitation is estimated to be 16 to 20 inches. Mean annual air temperature is less than 40°F; mean summer air temperature is 58 to 65°F.

This unit is used primarily for grazing cattle and sheep. If undisturbed, this unit would reach a stable plant community dominated by needleandthread. Most of this unit has been and still is heavily grazed by cattle and sheep.

II. Reclamation Considerations

A. Hazards and Risks

This unit is very fragile and disturbance would cause severe wind and water erosion of the shallow soils. The wind blows what little

soil that develops off the ridge where it accumulates on the leeward slopes allowing the establishment of taller sagebrush and serviceberry shrubs. Areas near the Cathedral Bluffs receive the most intensive wind erosion.

Any physical soil disturbance on this unit would bring the very gravelly subsoil to the surface producing a poor growth medium for plants. Drought, high winds, shallow and gravelly soil, exposure to temperature extremes, low soil loss tolerances, and a remote location make revegetation extremely difficult and any disturbance extremely hazardous.

Development of tailing ponds, mine dumps, roads and excavations have severe limitations due primarily to shallow depth to rock. These areas are small and any disturbance would affect the surrounding areas. Dumping of mine spoils on the leeward slopes and in the valley heads adjacent to the ridgetops would be less likely to erode than if dumping occurred further downstream in the watershed; however, diversions are needed to divert water flow around these areas.

B. Revegetation Requirements and Alternatives

Fertility levels for phosphorus are medium, indicating that only low phosphorus-requiring plants can be planted without application of phosphorus fertilizer. Potassium levels are high so that most species used for revegetation do not require potassium fertilizer. Application of nitrogen may not be necessary and if applied, weed invasion could become a problem.

Fertilizer should be applied prior to planting or at the time of planting to allow placement at the proper depth. Fertilizer applied to

the surface would be lost by wind and water erosion. Thirty pounds of phosphorus fertilizer (P_2O_5) per acre is recommended. When nitrogen fertilizer is utilized application should follow emergence of seeded plants.

Application of mulches would be desirable and often necessary to establish a satisfactory stand of seeded plants. Mulches conserve soil moisture and help minimize erosion. Straw mulches worked into the soil but not buried would be the most desirable. Planting, if in rows, should be perpendicular to the prevailing easterly wind in a rounded or corrugated furrow pattern. This furrowed surface effect would cause blowing soil material to settle in the depressions. Planting on the leeward side of these furrows would be most successful where neither excessive erosion or accumulation would be a problem. The "micro east" aspect thus provided would also provide a more optimal moisture environment for seedling establishment. Steep slopes greater than 20% should be planted on the contour and mulched for wind protection. More gentle slopes would be preferred, however.

Snow fences could be constructed on these ridges, perpendicular to wind direction to hold the winter snow and thus increase soil moisture recharge. This would increase moisture available to plants for revegetation and reduce the effect of blowing soil damaging seedlings. Planted areas need to be fenced for protection from livestock for at least one and perhaps as much as three growing seasons.

The following tables, numbered as they occur in the Handbook, provide descriptive vegetation (Table 66) and soils data (Tables 67, 68, and 69) for the Grassland Ecosystem Unit.

III. Vegetation

Table 66. Total standing crop green weight biomass, percent composition and percent constancy for RMU-17.

Total estimated range in standing crop green weight biomass is 600-1800 lbs./acre, with a mean of 1150 lbs./acre.[1]

Number of Stands: 4

Species	% Composition	% Constancy[3]
Shrubs and Trees		
Artemisia frigida	4.5	100
Ceratoides lanata	1.9	25
Chrysothamnus viscidiflorus	3.6	75
Phlox multiflora	2.7	50
Phlox longifolia	+[2]	25
Grasses and Grasslikes		
Koeleria cristata	14	75
Stipa comata	10.6	75
Agropyron smithii	8.9	75
Oryzopsis hymenoides	3.3	100
Poa secunda	3	50
Forbs		
Haplopappus nuttallii	10.3	75
Penstemon caespetosus	9	100
Hymenoxys acaulis	11.8	50
Eriogonum tristicum	4.7	75
Linum lewisii	1.6	25
Astragalus tequitarius	2.2	25
Crepis acuminata	1.2	25
Cryptantha sericea	+	75
Astragalus diversifolius	+	50
Eriogonum spp.	+	25
Penstemon stricta	+	25
Cirsium spp.	+	25
Trifolium gymnocarpon	+	25
Chaenactis douglasii	+	25
Taraxacum officinale	+	25
Artemisia ludoviciana	+	25
Comandra umbellata	+	25

Table 66.--Continued

Species	% Composition	% Constancy
Hedysarum boreale	+	25
Astragalus boreale	+	25
Number of other species = 1	+	
Total % Composition of species with less than 1% composition each marked with "+" =	5.0	

[1]Based upon 1975 which received nearly average to slightly below average precipitation.

[2]"+" indicates less than 1% composition.

[3]% Constancy is the percent of stands sampled that the particular species was found to be present.

Table 67. Laboratory data and relative ratings for RMU-17.[1]

Horizon		A1	C						
Depth in Inches		0-3½	3½-11						
pH (Paste)		7.2 neutral	7.6 mildly alkaline						
E.C. mmhos/cm (salinity class)		0.7 none	0.4 none						
Saline/Alkaline		non	non						
SAR		good 0.19	good 0.64						
ESP		---	---						
% Lime		high 2.0	high 9.4						
% Base Saturation		79	100						
% Organic Matter		high 6.0	high 4.2						
% Organic Carbon		3.53	2.47						
% Total N		0.460	0.325						
C/N		good 8.02	good 7.6						
P ppm		high 14.8	low 4.8						
K ppm[2]		high 222.3	low 58.5						
NH_4OA Extractable Cations meq/100 g	K	0.57	0.15						
	Na	0.14	0.41						
	Mg	2.64	2.88						
	Ca	24.58	32.93						
H_2O Soluble Ions meq/l	SO_4	0.77	0.84						
	Na	0.38	1.10						
	Mg	1.24	.90						
	Ca	6.73	4.98						
CEC		35.34	35.24						
% Sand		57	61						
% Silt		38	37						
% Clay		5	2						

[1] Definition of terms in the soil section of "How to Use the Handbook" part (b).

[2] Calculated from meq/100 g.

Table 68. Soil properties for RMU-17.[1]

Depth in Inches	USDA Texture	Unified	AASHO	% by Wt. Coarse Fragments >3"	% by Wt. Coarse Fragments >2 mm
0-3½	very gravelly sandy loam	SM, SC	A-1	5	50
3½-11	very gravelly sandy laom	SM, SC	A-1	50	80

Depth in Inches	% Material Less Than 3" Passing These Sieves				Liquid Limit	Plasticity Index	Permeability In/Hr	Available Water Capacity	
	(5.0 mm)	(2.0 mm)	(0.4 mm)	(.08 mm)				In/In	Total Soil
0-3½	55-75	40-50	25-35	10-20	15-25	0-5	0.6-6.0	.04-.09	1-1.5
3½-11	50-70	45-55	30-40	10-20	15-25	0-5	0.6-6.0	.05-.07	

Depth in Inches	Shrink Swell	Corrosivity		Erosion Factor		Wind Erod.	Shear Strength	Compressibility
		Steel	Concrete	K	T			
0-3½	very low	moderate	moderate	.27	1	T./ac./yr.	med	low-med
3½-11	very low	moderate	moderate	.27		117-180	med	low-med

Depth in Inches	Perm. of Compacted Soil (seepage)	Susceptibility to Piping	Compaction Characteristics	Depth and Hardness of Bedrock	Potential Frost Action	Flooding
0-3½	med-low	med	good	10"	low	none
3½-11	med-low	med	good	rippable		

[1]For explanation of properties see soil section of "How to Use the Handbook" part (c).

Table 69. Soil limitations for RMU-17.[1]

Use		Rating	Problems, each alone sufficient for the classified rating
Septic Tank Absorption Fields		Severe	Depth to rock, slopes over 15%
Sewage Lagoons and Tailing Ponds		Severe	Depth to rock, slopes over 7%, coarse fragments
Landfill	Trench	Severe	Depth to rock, slopes over 15%
	Area	Severe	Hard to reclaim, slopes over 15%
Cover for Landfill		Poor	Thin layer, area reclaim, slopes over 15%
Shallow Excavations		Severe	Depth to rock, slopes over 15%
Buildings without Basement (Dwelling Size)		Severe	Depth to rock, slopes over 15%
Buildings with Basements		Severe	Depth to rock, slopes over 15%
Small Commercial Buildings		Severe	Depth to rock, slopes over 7%
Local Roads and Streets		Severe	Depth to rock
Trafficability		Good	
Source Material	Roadfill	Poor	Areas hard to reclaim, slopes greater than 15%, excess fines
	Sand and Gravel	Poor	Areas hard to reclaim, excess fines
	Topsoil	Poor	Thin layer, small stones, area reclaim
Ponds and Reservoirs			Depth to rock, steep slopes
Embankments, Dikes & Levees			Thin layer
Excavated Ponds Aquifer Fed			No water
Drainage			Not needed
Irrigation			Soil blowing, complex slopes, depth to rock, shallow rooting depth, too fast water intake, droughty
Terraces and Diversions			Not needed
Establishment of Grassed Areas			Droughty, shallow rooting depth, steep slopes

Table 69.--Continued

Use		Rating	Problems, each alone sufficient for the classified rating
Recreation	Camp	Severe	High winds, soil blowing, slopes over 15%
	Picnic	Severe	Soil blowing, high winds, slopes over 25%
	Playground	Severe	Depth to rock, slopes over 6%
	Trails	Slight Moderate Severe	Slopes less than 15% (Most of the unit is less than 15% slope making trail locations desirable especially due to viewpoint potential.) Slopes 15-25% Slopes 15+%

[1]For explanation of limitations see soil section of "How to Use the Handbook" part (d).

WILDLIFE HABITAT SUITABILITY

Habitat Elements:

Grain and Seed	Grass and Legume	Wild Herb	Hardwood Trees	Conifer Plants	Shrubs	Wetland Plants	Shallow Water
Very Poor	Poor	Poor	Very Poor	Very Poor	Poor	Very Poor	Very Poor

Potential as Habitat for:

Openland Wildlife	Woodland Wildlife	Wetland Wildlife	Rangeland Wildlife
Very Poor	Very Poor	Very Poor	Poor

SUBPROJECT B

LONG-TERM FERTILITY MAINTENANCE ON LAND DRASTICALLY DISTURBED BY OIL SHALE DEVELOPMENT

PERSONNEL

Dr. Burns R. Sabey, Professor
Dr. William A. Berg, Associate Professor

TIME EXPENDED BY CO-INVESTIGATORS FOR CURRENT TERM

Dr. Sabey--none
Dr. Berg--none

Neither investigator was alloted time during the 1976 funding period.

OBJECTIVES

Long-term fertility requirements and methods of meeting these requirements on deficient soil materials disturbed by oil shale development in northwestern Colorado will be determined.

PROGRESS TO DATE

Processed shale from the Paraho retort facility will not be available in sufficient quantities to fulfill the required research design until summer, 1977. Therefore, field studies were not activated this past season and efforts were concentrated on preparation for the coming one. An extensive review of literature relative to this subproject was conducted and completed. The design for the configuration and structure of the plot is complete and sampling methods have been determined. These are outlined in the Renewal Proposal. Equipment for determing fertility

levels (Block Digestor) is currently being assembled. The purchase and transport of fertilizers, sewage sludge, and wood chips has also been arranged.

SUBPROJECT C

THE ROLE OF SOIL MICROORGANISMS AS INDICATORS AND POSSIBLE CONTROLLING FACTORS IN PLANT SUCCESSION PROCESSES ON DISTURBED SOILS

PERSONNEL

Dr. Donald A. Klein, Associate Professor
Dr. James P. Nakas, Research Associate
Mr. Nicholas Nagle, Research Technician
Ms. Linda Smith, Research Assistant

TIME EXPENDED BY CO-INVESTIGATOR FOR CURRENT TERM

Dr. Klein--100% time for .5 months

OBJECTIVES

1. To monitor microbial activities and characteristics in revegetation plots which have been in place for four to five years at the study area, to determine characteristics of the microbial populations and their capabilities.
2. To evaluate microbial responses and changes in numbers and activity during reestablishment of plant communities on disturbed soils, using the annual disturbance, successional, revegetation technique and spent shale successional plots which are being developed at the intensive study site.
3. To develop techniques for evaluating the ability of specific plant types to stimulate nitrogen fixation in the rhizosphere.
4. In laboratory test systems, to determine the role of plant material decomposition on microbial processes. This portion of the work will

utilize plant materials derived from laboratory and field studies to determine if breakdown products from different plant types will have specific effects on nitrogen fixation and nitrification activities.

PROGRESS TO DATE

During the first year, the major effort was directed towards development of techniques which will be used during the spring of 1977 at the intensive study site. Field and laboratory studies were completed to gain information on the following parameters; on existing revegetation plots:

- Soil bacteria and actinomycetes on a sodium caseinate medium
- Fungi by use of a rose bengal medium
- Nitrifiers by a most-probable-number assays
- Nitrification activity by measurement of ammonia oxidation rates
- Evaluation of fungal versus bacterial contributions to carbon flow processes.

The major goal of this subproject is to determine which rehabilitation techniques will lead most rapidly and efficiently to soil which will be capable of providing microbial nutrient cycling and energy flow typical of mature ecosystems.

MATERIALS AND METHODS

Soil Samples

Soil samples have been taken from the following test sites:

Plot Numbers	Site	Number of Samples Taken
1	Low Sagebrush	36
2	Low Pinyon-Juniper	48
3	High Pinyon-Juniper	48
4	High Mountain Browse	36
5	High Elevation Processed Shale (Black Sulfur)	28
6	Anvil Points Processed Shale Plot	28
7	Successional Test Plots	8
8	Revegetation Technique Plots	18
9	Annual Disturbance Plots	36

The plots 1-6 were sampled during the summer and fall of 1976, and the plots 7-9 were sampled during the first part of January, 1977, to provide background information on microbial populations in the soils prior to the beginning of plant growth in spring.

At the sampling sites 1-4, marker posts were set up at the ends of each replication plot set, and 1.5-2.0 kg samples (0-10 cm depth) were taken at the center of each sub-plot, avoiding plant growth in the first preliminary sampling. The samples were stored at room temperature in self-sealing plastic bags during and after transport to the laboratory. Samples were held in larger plastic bags with added excess water to maintain the soils in a humidified environment.

Sample sets 5 and 7 were taken at the center of each of the sub-plots, again avoiding excess plant growth. For the initial samples at the intensive study area, approximately one-third of the possible plots for each of the test areas were taken. After receipt at the laboratory, all soil samples were sieved, using a 2 mm mesh sieve to remove rocks,

roots and other debris. The samples were then stored at room temperature in self-sealing bags.

Soil Microbial Enumeration Techniques

Fungi were enumerated using Rose Bengal Agar, consisting of 10 mg of dextrose, 5 gm peptone, 1.0 gm of monobasic potasium phosphate, 0.5 gm $MgSO_4 \cdot 7H_2O$, 0.33 gm of Rose Bengal, 20 gm of Agar and 1,000 ml of deionized H_2O_2. This was sterilized, and after cooling, 3 ml of streptomycin solution was added to the media, using procedures of Martin (1950). The actinomycetes and bacteria were enumerated with sodium caseinate agar, consisting of .2 gm sodium caseinate, 5 gm K_2HPO_4, .2 gm $MgSO_4 \cdot 7H_2O$, .01 gm of $FeCl_3$, 15 gm of agar and 1,000 mg of H_2O.

Eleven grams of the sifted soil was poured in a standard phosphate dilution blank and shaken for 15 minutes on a reciprocal shaker at 124 rmp, diluted, and inoculated onto spread plates using 0.1 ml aliquots. Plates were incubated at room temperature for two weeks before being counted, to assure maximum expression of colonies.

pH

Soil pH was taken by pouring 50 ml of the soil solution from the enumeration bottle and was then stirred until a stable reading was observed on the pH meter.

Organic Matter

The sifted soil was weighed out in three 0.3 gm amounts to which 3 ml of 1 N potassium dichromate was added. Six ml of conc. H_2SO_4 was quickly added, swirled for 10 seconds, and allowed to stand for 10 minutes, after that time 30 ml of H_2O was added. The solution stood

overnight to allow the sediment to settle. Five ml of the solution used to read the absorbance at 610 nm using a Bausch and Lomb spectrophotometer. Standard soils containing 1 and 2% organic matter, obtained from the Colorado State University soil testing laboratory, were used as standards.

Nitrate Activity Assay

Nitrification activity was assayed by adding 50 gm portions of the test soils to 4 petri plates, with three being replicates and the fourth being a control. To the three experimental soil samples, 10 ml of ammonium sulfate solution, .5 gm K_2HPO_4, 5 gm $(NH_4)_2S_4$, 1,000 ml H_2O were added to the soil using a syringe to cover the entire surface of the plate. The plate was covered and placed in a sealed incubator at room temperature, which was kept humid by trays of water. At two week intervals 14 gm aliquots were air dried and analyzed for nitrate using the Orion nitrate electrode model #93-07 and Orion reference electrode model #90-02, connected to a Corning pH/mv meter. The soil sample was emptied into a flask to which was added 50 ml H_2O, .5 ml AgF, .5 ml KF, .5 ml of conc. acetic acid, and 1 gm CaOH. The flask was shaken on a reciprocal shaker at 125 rpm for 30 minutes and filtered through Whatman #1 filter paper. The nitrate electrode was lowered into the filtrate and millivolts were recorded and read against a standard curve for nitrate to determine μg NO_3^-N per gm soil.

Nitrogen Fixation

Nitrogen fixation activities of soils and plants have been carried out using procedures provided by Hardy et al. (1968) and Hardy, Burns and Holsten (1973). Specific equipment used in the laboratory includes a

Varian Herograph model 1200 flame ionization gas chromatograph, and an integrator-recorder to allow calculation of peak areas. Standards of acetylene and ethylene were obtained from the Applied Science Laboratories, State College, Pennsylvania.

The separation of acetylene from ethylene was carried out by use of a 1/8x6 foot stainless steel column of Poropak Q (Water Associates, Mildord, Massachusetts) with a column bath temperature of 70°C.

Separation of Fungal vs. Bacterial Contributions to Mineralization Processes

To determine the possible changes in fungal versus bacterial contributions to mineralization processes in test soils, the basic radiotracer mineralization procedure of Harrison, Wright and Morita (1970) has been combined with the antibiotic additions suggested by Anderson and Domsch (1973), using a 20 minute incubation period.

Results to Date

Existing treatment plot analyses. To the present time, basic analyses have been completed for four of the plots. Generally, data from the revegetation plots that have been in place for 4-5 years suggest that the soils in the native (undisturbed), scraped, and plowed areas, both in favorable and unfavorable aspects (north and south facing slopes), do not show major changes in decomposer characteristics in relation to management and topographic variables.

The data for the low sagebrush plot (84 Mesa area) are given in Table C1. For the favorable aspect samples, the scraped soils sub-plots show a trend towards slightly high fungal, bacterial and actinomycete populations, although the standard error values indicate that these are

not particularly strong. A similar trend is suggested for the unfavorable aspect plots, although again this is not strong. For the organic matter and pH values, the only point of interest is the decreased organic matter levels on the native and plowed areas, and generally higher pH values on the unfavorable aspect and slope samples, being in the range of 8.3-8.5.

This same trend is shown for the samples for the low elevation pinyon-juniper plot (Table C2), where the soils from unfavorable (south aspect) slopes have higher pH values. Another point of interest is that the microbial populations for the scraped and plowed sub-plots tend to have higher microbial populations, although with the standard error values, these are not significant. No clear trends are evident for the nitrification values, which were read at six weeks of incubation.

Available data for the retorted shale revegetation technique plots at the anvil point site are summarized in Table C3. The major point of interest is the significant decrease in fungal populations in soils which had U.S. Bureau of Mines (USBM) materials added, except where the materials were covered with 24 inches of topsoil, and the significant increases in organic matter in the plots which contained higher concentrations of the retorted shale material. This is probably a reflection of the 3-6% residual carbon left in the spent shale following retorting.

The data which are available for the Black Sulfur Creek shale rehabilitation site are presented in Table C4. In comparison with controls, there appears to be a slight trend towards decreased fungal populations in USBM retorted shale materials used, and a suggestion of higher bacterial populations. On this plot the USBM materials showed a higher pH range, as indicated in Table C4. In addition there was a significant

Table C1. Microbiological characteristics of rehabilitation plot soils at 84 Mesa site (Plot #1).[a]

Aspect Treatment	Microorganisms/gram soil			Soil Organic Matter	Soil pH	Nitrification Rates
	Fungi x 10^{-4}	Bacteria x 10^{-6}	Actinomycetes x 10^{-6}			
Favorable						
Scraped	1066.0±22.0	19.8±1.4	24.7±2.3	1.57±0.14	7.8	-[b]
Native	37.4± 3.8	17.4±2.2	22.6±3.9	1.64±0.01	7.7	-
Plowed	38.7± 2.5	28.8±3.8	17.0±1.9	1.73±0.11	7.8	-
Unfavorable						
Scraped	53.8± 2.7	30.0±3.9	29.0±3.9	1.90±0.21	8.3	-
Native	50.9± 5.3	27.9±2.8	36.1±4.7	1.13±0.06	8.6	-
Plowed	45.0±15.3	36.2±3.5	43.0±7.8	0.92±0.07	8.5	-

[a]Source Book 76-13. Total sub-plots = 36, mean and standard errors given.

[b]Data analysis not complete.

Table C2. Microbiological characteristics of rehabilitation plot soils at the Low Pinyon-Juniper plot.

Aspect Treatement	Microorganisms/gram soil			Soil Organic Matter	Soil pH	Nitrification Rates
	Fungi x 10^{-4}	Bacteria x 10^{-6}	Actinomycetes x 10^{-6}			
Favorable						
Native	28.08±5.00	22.20± 3.19	28.47±2.07	3.36± .62	8.3	3.99±1.99
Scraped	39.77±8.84	28.57±11.66	46.83±5.33	3.35± .62	8.3	2.88±1.29
Plowed	90.55±4.96	34.10± 5.51	44.98±7.2	2.96± .32	8.4	4.11± .68
Unfavorable						
Native	36.98±6.55	21.77± 1.82	30.43±1.52	3.29±1.16	8.7	1.35± .251
Scraped	42.01±1.63	24.34± 3.31	26.5 ±2.33	3.68± .31	8.5	3.54±1.06
Plowed	44.8 ±8.52	24.63± 1.73	33.23±1.42	3.65± .23	8.6	3.65± .83

Source: Book 76-13. Mean and standard errors given.

Table C3. Microbiological characteristics of retorted shale rehabilitation plots at Anvil Points site (Site #7).[a]

Aspect	Treatment		Microorganisms/gram soil: Fungi x 10^{-4}	Bacteria x 10^{-6}	Actinomycetes x 10^{-6}	Soil Organic Matter	Soil pH	Nitrification Rates
Control Soils		N	22.9 ±11.5	46.5 ±10.38	62.65± 3.66	2.85±.56	7.6	-[b]
		S	40.3 ±32.3	32.5 ±13.5	41.95±10.68	3.07±.66	7.9	-
USBM Materials								
	Spent shale leached	N	4.84± .01	33.4 ± 6.92	40.77± 5.24	5.70±.60	8.0	-
		S	3.37± .275	15.75± 2.25	34.25± .75	5.33±.07	8.1	-
	Leached 6" soil cover	N	7.80± 1.00	36.25± 7.27	48.0 ±10.03	3.36±.19	8.3	-
		S	5.34± 1.71	34.50± 9.02	69.2 ±14.29	3.01±.506	8.0	-
	Not leached 24" soil cover	N	14.1 ± .50	38.25± 2.25	45.5 ± 1.50	3.18±.03	8.2	-
		S	27.8 ±16.4	17.7 ± 1.75	26.0 ± 2.00	2.75±.220	8.2	-
TOSCO Materials								
	Spent shale leached	N	67.9 ± 2.87	18.37± 9.65	106.00±63.18	7.07±.160	7.8	-
		S	26.9 ±12.5	30.5 ± .50	58.25± .250	7.11±.401	7.8	
	Leached 6" soil cover	N	13.2 ± .601	31.80± 5.21	55.80±10.28	4.59±.611	8.2	3.70±1.35
		S	11.6 ± .90	44.00± 4.01	62.25± 7.75	2.92±.280	8.4	4.19± .967
	Not leached 12" soil cover	N	17.70± 2.35	22.5 ± 3.96	45.8 ± 6.82	3.93±.21	6.9	4.79± .772
		S	13.6 ± 1.40	33.60± 5.06	52.2 ± 4.76	2.5 ±.641	7.1	-

[a]Source Book 76-13. Means and standard errors given.

[b]Data analysis not completed.

Table C4. Microbiological characteristics of retorted shale rehabilitation plots at the Black Sulfur Creek site.[a]

Aspect Treatment		Microorganisms/gram soil			Soil Organic Matter	Soil pH	Nitrification Rates
		Fungi x 10^{-4}	Bacteria x 10^{-6}	Actinomycetes x 10^{-6}			
Control Soils	N	35 ± 3.4	264±109	475±115	1.80±0.11	7.7	-[b]
	S	30 ± 0.4	224± 89	342± 82.7	1.90±0.16	7.3	-
USBM Materials							
Spent shale leached	N	32 ±23	395± 5	565±165	5.54±0.14	8.0	-
	S	26 ±10	460± 85	767± 27	5.32±0.18	8.2	-
Leached 6" soil cover	N	48 ±14	340± 95	535± 90	1.74±0.05	7.8	-
	S	6.1± 1.7	242± 33	279± 24	1.92±0.21	6.9	-
Not leached 12" soil cover	N	6.1± 1.3	350± 99	631±253	1.89±0.15	7.5	-
	S	5.6± 1.4	609±163	531±400	1.90±0.16	7.4	-
TOSCO Materials							
Spent shale leached	N	42.5± 5	271±244	422±322	7.55±0.06	7.4	-
	S	31.0± 0.5	347± 28	732± 8.2	7.53±0.01	7.4	-
Leached 6" soil cover	N	43.3±27	206± 53	347± 48	1.96±0.07	7.8	
	S	39.8± 4	233± 20	449± 43	1.91±0.08	7.7	-
Not leached 12" soil cover	N	31.3± 7	367±157	348±195	2.25±0.07	7.6	-
	S	3.2± 0.2	140± 50	283± 83	3.06±0.52	7.7	-

[a]Source Book 76-84, 28 samples analyzed. Means and standard errors given.

[b]Data analysis not completed.

increase in organic matter in the TOSCO and USBM materials, based on the assay used in this study. Again, this was most likely caused by residual carbon in the spent shale. Thus, at least with use of the USBM type materials, it would appear that there are changes in microbial populations which may persist over longer time periods in spite of the intensive management which was used on these test sites, including fertilization, leaching, and seeding.

Intensive Study Area Samples

The samples from the intensive study area, which were taken on January 7, 1977, are being analyzed at the present time, and these data will be available for the final report from the first year of studies.

Nitrogen Fixation Studies

Results available to date suggest that the techniques which have been developed will be adequate to detect nitrogen fixation in soils and plant root samples. Calculations available at the present time suggest that it will be possible to detect nitrogen fixation at rates as low as 0.01 μ moles C_2H_2 reduced$\cdot min^{-1}\cdot$mg fresh plant material^{-1}.

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SUBPROJECT D

PLANT MATERIALS--ECOLOGICAL-GENETIC VARIATION OF IMPORTANT NATIVE SPECIES, SELECTION AND PRODUCTION OF PREADAPTED PLANTS FOR RECLAMATION, AND THEIR INTEGRATION WITH LANDSCAPE-VEGETATION PATTERNS.

The presence of genetic differences between populations of native species is important for reclamation because it means that there are different adapted forms which will have varying potential for reclamation of different sites. These differences in potential are especially important if they are expressed through differences in ecological position within the vegetation or landscape.

The identification, characterization, and propagation of many populations of a species, each with unique reclamation possibilities, is a step in the direction of more controlled and predictable reclamation technology. It is also an essential first step towards the artificial breeding and selection and maintenance of plant forms with special relevance to reclamation. Understanding the different vegetation-landscape relations of each ecotype is desirable because vegetation structure, if known, is a sensitive indicator of the complex environment to which the ecotype is adapted. Further, the predisturbance vegetation of a site to be reclaimed will reflect the general nature of the environment within which the reclaimed communities will be developed.

Two separate investigations of plant materials follow. The first (DA) deals with legumes, forbs, and grasses, and the selection and production of preadapted types for reclamation. The second (DB) deals with

the identification and interpretation of ecotypic variation of shrubs and provides a phytosociological background for understanding the ecologic position of the species investigated in both sections.

SUBPROJECT D(A)

SELECTIVE BREEDING OF GRASSES, LEGUMES, AND FORBS TO DEVELOP IMPROVED STRAINS THAT CAN BE ESTABLISHED ON DISTURBED SITES IN OIL SHALE AREAS TO PRODUCE A STABILIZED ECOLOGICAL COMMUNITY.

PERSONNEL

Dr. Robin Cuany, Associate Professor
Mr. Walter Padilla, Research Assistant

TIME EXPENDED BY CO-INVESTIGATOR FOR CURRENT TERM

Dr. Cuany--100% time for 1 month

OBJECTIVES

1. Collect and assemble germplasm sources.
2. Evaluate spaced plants in two nurseries, and clonal propagules or progenies under controlled stress.
3. Evaluate seeded progenies in intensive site and satellite field plantings.
4. Use suitable breeding procedures for recombination and progeny testing to develop improved strains.
5. Coordinate research on best means of multiplying and planting the improved strains.

PROGRESS TO DATE

Germplasm Sources and Collections

The proposed list of species to be tested remains unchanged until field evaluations in progress should indicate any alteration or

reemphasis. Present studies are concentrated on the following species, listed below in the order of their priority.

Common Name	Botanical Name
Grasses:	
1. Western wheatgrass	*Agropyron smithii*
2. Indian ricegrass	*Oryzopsis hymenoides*
*3. Kentucky bluegrass	*Poa pratensis*
4. Sheep fescue	*Festuca ovina*
*5. Hard fescue	*F. ovina duriuscula*
Legumes:	
1. Lupine	*Lupinus* spp.
2. Utah sweetvetch	*Hedysarum boreale utahensis*
*3. Cicer milkvetch	*Astragalus cicer*

The western wheatgrass and Indian ricegrass have received most attention to date in the grasses as have lupines in the legumes. Other species will receive more concentrated study in future efforts.

The germplasm sources differ among each species: Table D(A)1 lists origins and approximate number of sources obtained for each species. Further source collections will be made in and outside of Colorado. A few accessions with small amounts of seed have been lost due to aged seed, dormancy problems, and disease problems of seedlings in the greenhouse. Some potential native seed sources could not be tapped, due to unfamiliarity with their locations and phenological patterns in the 1975 season, and low seed production in the 1976 season. Every native collection involves acquiring at least two live specimens and seed if available. The

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*Those marked by asterisks are introduced, not native. Bluegrass and fescues are of secondary importance.

Table D(A)1. Seed sources and number obtained from each.

Species	Source					
	WRPIS[1]	SCSPMC[2]	Named Varieties	Fellow Researchers	Colorado Collections	Commercial Lots
Western wheatgrass	4	15	5	33	43	
Indian ricegrass	12	8	1	2	31	2
Kentucky bluegrass	58		7	50	2	
Sheep fescue	14	1			4	
Hard fescue		2				
Lupine					40	
Utah sweetvetch					10	
Cicer milkvetch		1		7		

[1]Western Regional Plant Introduction Station.

[2]SCS Plant Materials Center.

live specimens are kept in a collection nursery (which can also produce seed) at the CSU Agronomy Research Center in Fort Collins, Colorado.

Most of the Colorado collections listed as sources for many of the species were made by the co-investigator and/or his graduate research assistant. Ten collection trips were made in 1975 and seven trips in 1976. Collections were conducted in the Piceance Basin and neighboring areas (e.g. Battlement Mesa, Douglas Creek, and Meeker area), and various other locations scattered over the entire state (e.g. San Luis Valley, South Park, North Park, near Colorado Springs, and Colorado City). A late frost in the spring of 1976 severely damaged lupine seed set at the lower elevations in the Piceance Basin. Seeds were therefore collected only from plants at higher elevations (above 2,236 meters).

Breeding Nurseries

From acquired germplasm, seedlings were grown in a greenhouse during winter, 1975-1976, for 1976 nursery transplanting. An Indian ricegrass nursery of 16 sources (20 plants per source) and a western wheatgrass nursery of 47 sources were established in Fort Collins in summer 1976, along with two western wheatgrass nurseries in Meeker at the SCS Upper Colorado Environmental Plant Center. One Meeker nursery consists of 56 sources of adult plants (taken from a three year old Great Plains ecotype nursery) and the other contains 25 sources of western wheatgrass seedlings as a partial replicate of the Fort Collins seedling nursery. The nursery plants are being evaluated for rhizomatous spread, survival, disease incidence, height, seed set, and seed quality. Notes on general morphological characteristics and flowering periods are also being taken.

The results are to be compared with 1975-1976 data on the 800 plants of the Great Plains source nursery.

There is evident genetic variation in *Agropyron smithii* among the Great Plains sources, some from as far north as Alberta, for color of foliage (waxiness), degree of rhizomatous spread, time and extent of flowering--which may be a latitude/photoperiod response--and percent seed set. Differences were also observed in susceptibility to stem rust (causal organism *Puccinia graminis*) and to ergot (*Calviceps* spp.). Whether these differences are maintained at the Meeker and Fruita plantings remains to be seen. Results may dictate not only the choices of parent plants but also the best location for seed increase of newly synthesized strains.

The results are less complete for the Indian ricegrass nurseries which were established in fall, 1976, and whose characteristics are to be studied in detail in spring, 1977, and subsequent seasons. Additional nurseries will be made as other sources provide adequate seed. A lupine nursery is scheduled for spring, 1977, and establishment in greenhouse pots for flowering, incompatibility testing and other controlled pollinations is currently in progress.

The seed which has been harvested from the older nurseries, and processed to remove empty florets and other inert matter, is material for selection of the parent plant as an elite parent for further breeding manipulation. Characters being surveyed are seed size, relative seedling vigor in optimum germination conditions, and germination response to salinity or other stress tests. These tests for western wheatgrass, Indian ricegrass and lupines are scheduled in the early months of 1977. Seed size ranges are being compiled. For example, among 9 lupine

populations the average weight per seed ranged from 10 to 36 mg with grand mean of 20 mg.

Dormancy breaking treatments are under study for Indian ricegrass. The purpose is to select the most effective treatment of seed for establishing nurseries and seeded trials, as well as breeding for improved germination. The treatment for lupine seeds is mild scarcification of the seed wall followed by soaking so that swollen seed can be planted in pots (the seed for field trials has, of course, to be left dry). A certain proportion of "hard" seed is probably an advantage for reclamation use, however.

Site Seedings

We have sown row-seeding trials in the Piceance Basin involving germplasm sources of all the species listed earlier, except lupines (Table D(A)2). These trials are at the intensive study site (2,042 meters) and at a mountain browse community site (2,438 meters) on areas scraped prior to seeding. Evaluation criteria will be essentially the same as for the nurseries, but will stress emergence, adaptation and survival. Considerable drought stress can be expected from the 1976-1977 winter.

The three types of crownvetch (a Eurasian species) are the three named varieties available in the trade--Penngift, Emerald, and Chemung, which have somewhat different growth habits. The Austrian pea is a legume, not native to this continent either, but adventive in fence rows and waste places, some saline, in the San Luis Valley near Mosca, Hooper, and Alamosa, Colorado. The adaptation of the three species of introduced legumes, including cicer milkvetch, needs testing while we are developing the native, localized strains of lupine and Utah sweetvetch.

Table D(A)2. Seeding trials in the Piceance Basin.

Botanical Name	Common Name	Number of Sources Planted	
		Intensive Site	Mountain Browse Site
Agropyron smithii	Western wheatgrass	25	23
Oryzopsis hymenoides	Indian ricegrass	18	17
Festuca ovina	Sheep fescue	1	1
F. ovina duriuscula	Hard fescue	1	1
Poa pratensis	Kentucky bluegrass	14	27
Cynodon dactylon	Bermuda grass	1	1
Astragalus cicer	Cicer milkvetch	7	7
Coronilla varia	Crownvetch	3	3
Hedysarum boreale utahensis	Utah sweetvetch	1	1
Swainsona salsula	Austrian pea	1	1
	Total	72	82

*Plots were 2 rows, 4.5 x .5 meters apart.

Breeding Procedures

Objective 4 involves the recombination of parent plants whose characteristics and progeny behavior have been measured for at least one or two seasons. Because of the time schedule involved, recombinations cannot be made before the second contract year, and this aspect is therefore treated in the Continuation Proposal.

Seed Multiplication Efficiency Testing

In September, 1976, a seed production trial began at the Fruita Experiment Station. Many different grass species used in revegetation or range seedings were sown; among these were 13 varieties and sources of western wheatgrass, 10 sources of Indian ricegrass, 3 varieties of Kentucky bluegrass, 1 source of sheep fescue, and 1 variety of hard fescue (Table D(A)3). These will be evaluated for establishment and seed production capacities. This trial should also enable us to sharpen our methodology of selecting for plant characteristics that make for good seed production in the breeding nurseries of the target species.

Table D(A)3. Species and varieties seeded at Fruita in September, 1976, for seed production tests.

Botanical Name	Common Name	Variety
Agropyron dasystachyum	Thickspike wheatgrass	Critana
A. desertorum	Crested wheatgrass	Ruff
A. inerme	Bluebunch wheatgrass	p-737
A. spicatum	Beardless bluebunch wheatgrass	Whitmar
A. riparium	Streambank wheatgrass	Sodar
A. smithii	Western wheatgrass	Arriba, Flintlock, Rosana, Mandan 456, + 9 others
A. trachycaulum	Slender wheatgrass	L333
Bouteloua gracilis	Blue grama	Lovington
Bromus inermis	Smooth brome	Lincoln, Manchar
Cynodon dactylon	Bermuda grass	Common
Elymus cinereus	Basin Wildrye	C-43
Eragrostis trichodes	Sand lovegrass	Nebraska 27
Festuca ovina	Sheep fescue	P-274
F. ovina duriuscula	Hard fescue	Durar
F. rubra	Red fescue	#10693
Oryzopsis hymenoides	Indian ricegrass	Paloma + 9 others
Phleum pratense	Timothy	Climax
Poa ampla	Big bluegrass	Sherman
P. compressa	Canada bluegrass	Common
P. pratensis	Kentucky bluegrass	Prato, Nugget, Newport
Sporobulus cryptandrus	Sand dropseed	Native
Stipa viridula	Green needlegrass	P-15637

SUBPROJECT D(B)

ECOLOGICAL-GENETIC VARIATION IN IMPORTANT NATIVE SHRUB SPECIES AND ITS INTEGRATION WITH LANDSCAPE-VEGETATION PATTERNS.

PERSONNEL

Dr. Richard T. Ward, Professor
Dr. Ralph L. Dix, Professor
Dr. William Slauson, Research Associate

TIME EXPENDED BY CO-INVESTIGATORS FOR CURRENT TERM

Dr. Ward--100% time for 1 1/2 months
Dr. Dix--100% time for 1 1/2 months

OBJECTIVES

The contributions basic biology can make to reclamation include: (1) baseline evaluation of genetic variability and potential of particular species for reclamation and (2) baseline definition of the ecological structures to be reclaimed. Such baseline definition, however, is not merely a cataloging and description of vegetation units which are congruent with the management units. Rather, it provides an ecological characterization of the communities within a landscape to be reclaimed in a way which emphasizes the structural and dynamic interrelations of the community. Further, it views the species' populations making up these communities as not necessarily genetically homogeneous. Our approach is twofold: (1) to evaluate the extent of ecotypic (genetic) variation across different populations of selected shrub species by growing representatives from different populations in a common environment and

(2) to develop an abstract gradient model of vegetation structure from original data using standard gradient analysis techniques.

PROGRESS TO DATE

Genetic-ecologic (Ecotype) Differentiation

The ecotype studies are designed to provide a better understanding of the biology of native shrub species, especially concerning the variety of adapted genetic forms, and information about this variation within the context of community and landscape structure. There are two levels of study: (1) ecotypic variation over a broad geographic range and (2) ecotypic variation within a local landscape unit. The first will use materials from Utah, Wyoming, and Colorado, and possibly New Mexico and Arizona. The second and most intensive level of investigation will be to examine ecotypic differentiation among populations collected along local environmental-vegetation gradients within the Piceance Basin.

The general strategy for discovering if variation among populations has a genetic base or is due to plasticity of expression of a common genotype is to grow, in a common environment, materials collected from different populations. Further, it is advisable to use vegetative materials rather than seeds for propagation in the common garden since the vegetative material is certain to be representative of a genotype that is adapted to its environment, while all possible recombinants represented by seed may not be so. Future studies to compare the variation within seed populations with variation in surviving plants are anticipated.

Since the techniques of vegetative propagation of the shrubs selected for study are little known, and since establishment of these

plants takes several years, our early efforts have been directed to learning how to root stem cuttings of the various species. Clippings of the current year's stems were treated with a commercial growth hormone and fungicide, inserted in a perlite medium, and placed under periodic mist in the greenhouse. Species used and results are as follows:

Symphoricarpos oreophilus--Snowberry

rooted in 3 weeks, potted and removed from mist in 8 weeks, alive after 15 weeks

Purshia tridentata--Bitterbrush

rooted in 3 weeks, potted and removed from mist in 8 weeks, alive after 15 weeks

Atriplex canescens--Four-wing Saltbush

rooted in 3 weeks, potted and removed from mist in 8 weeks, alive after 15 weeks

Atriplex confertifolia--Shadscale

rooted in 3 weeks, died at 8 weeks

Cercocarpus montanus--Mountain Mahogany

rooted in 3 weeks, potted and removed from mist in 8 weeks, failing at 15 weeks

Amelanchier alnifolia--Serviceberry

rooted in 7 weeks, potted and removed from mist in 13 weeks, alive after 15 weeks

Quercus gambellii--Gambel's Oak

died before rooting

Prunus virginiana--Choke cherry

died before rooting

Artemisia tridentata--Big Sagebrush

died before rooting

It is expected that use of the earlier softwood rather than the late-season hardwood cuttings and better control of rooting will allow the following schedule for preparation of transplant materials. Collection of softwood shoots and placement in the rooting bench in the greenhouse can be started in late spring. One to two months later, depending on development of roots, the plants can be potted and kept in the greenhouse. They will be ready for transplant in the study garden the following spring, or perhaps earlier if vigorous.

Due to the difficulty and length of time required to establish a garden of shrub species, and anticipating a lengthy period of field measurements before preliminary conclusions concerning shrub ecotypes can be made, the emphasis of the early stage of this study is to establish a variety of shrub species, from a representative range of environments, which will be available for measurements in future growing seasons. The species selected for study are:

Amelanchier alnifolia
Artemisia tridentata
Atriplex canescens
Ceratoides lanata
Cercocarpus montanus
Symphoricarpos oreophilus
Purshia tridentata

The major goal, then, for the first growing season is establishment of these species. In addition we are currently investigating a method of propagating *Symphoricarpos oreophilus* from late fall and winter cutting with the hope of getting some preliminary measurements in the first growing season.

Initially a single common garden for propagation and comparison of different source materials is planned and will be located within the Intensive Study Site in the Piceance Basin. Additional plantings of the studied shrubs will be made at the Meeker Plant Materials Center to be used for replacing damaged or inviable plants in the main garden. Other gardens may be established in the future; however, this is not a pressing need since our experience in other ecotype studies indicates that similar response trends are displayed in multiple gardens.

For each species at least 5 locations from a wide geographic range will be used. The area of interest is indicated in Figure D(B)1. For each of these collection sites, eight different individuals will be represented. Replication for one of the species will be used to test for garden homogeneity. Investigation of ecotypes along a local environmental gradient will initially involve only one or two species, which will be collected from 12-15 sites on a gradient determined in our phytosociological studies.

The specific measurements on the garden material will depend in part on what will be learned about the seasonal cycle and growth habits of each species, and will vary with the species. Measurements to reveal ecotypic differences in phenology, morphology, vigor and growth will be made, and will include the time growth starts, time of leaf expansion, cessation of stem growth, leaf fall, dormancy, leaf size, stem length growth and growth form. For plants which reach reproductive age, the time of flower budding, anthesis, fruit ripening, and seed and fruit characteristics will be measured. In addition, *Artemisia tridentata* and *Ceratoides lanata* strains which are known to differ in palatibility and

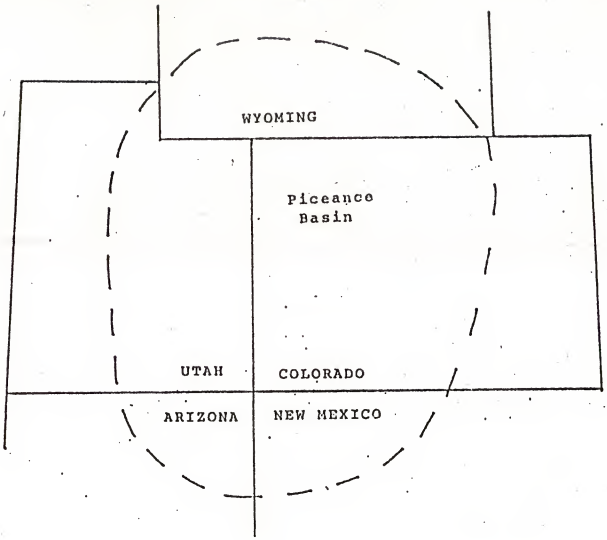


Figure D(B)1. Region of Collection Emphasis for Ecotype Studies.

response to grazing pressure will be maintained for further study of these traits.

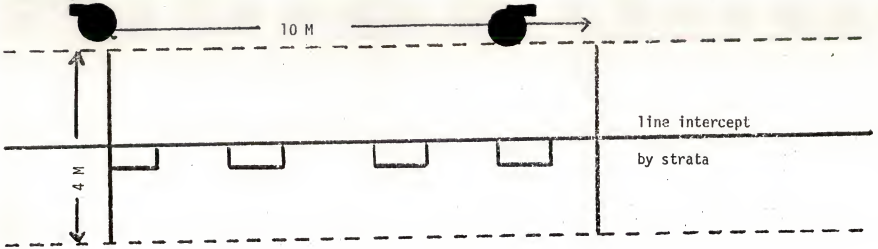
Gradients of Vegetation Structure

Our work to date relates to the phytosociological objectives in two ways. First is the compilation of a standardized floristic list and the initiation of a herbarium of voucher specimens. Second is the development of a sampling regime which will enable comparable treatment of the diverse community types present in the Piceance Basin. Nomenclature of the floristics list follows the usage of Dieter Wilken, Curator of the Colorado State University Herbarium. Names which are different from others in common usage are cross referenced. Verified specimens of the taxa are housed in the CSU Plant Ecology Laboratory, Plant Science Building. Collections by other investigators may be deposited here for verification and voucher reference.

A sampling procedure was developed to sample all the strata of a given community and to provide data appropriate to cross community comparisons even where the communities are of a different life form. The data will be amenable to standard phytosociological techniques of analysis and provide information for structural analysis. In addition environmental measurements will be made which will aid in the interpretation of major axes of variation. These methods are described below.

Stands (areas of homogeneous vegetation) are the basic sampling units. They are kept as small as practical, an average .2 hectares for this study.

The sampling regime consists of three parts: a line intercept to measure shrubs; a set of large area quadrats to measure trees, and a set of small quadrats to measure the understory (Fig. D(B)2). First, a



Area Quadrats

Tree species 4 x 10 quadrats

	Trees Basal areas	Saplings Number	Seedlings Number
Douglas Fir	>10 cms dbh	<10 cms dbh;> 1 m tall	>1 m tall
Aspen	>10 cms dbh	<10 cms dbh;> 1 m tall	>1 m tall
Cottonwood	>10 cms dbh	<10 cms dbh;> 1 m tall	>1 m tall
Pinyon	>2 m tall	<2 m tall	>1 m tall
Juniper	>2 m tall	<2 m tall	>1 m tall

Herb species 0.5 x 1.0 quadrats

Frequency data

Line Intercept

All tree and shrub species by strata (50; 50-150; 150 cms)

Figure D(B)2. Composite Sampling Regime For Tree, Shrub and Herbaceous Species.

steel tape (a 30 m tape was found most useful) is stretched through the stand to form a line. A pole, two meters long and held perpendicular to the tape, is used to project the cover of all shrub species onto the line. The pole is marked with colored tapes at 0.5 m and 1.5 m so that each cover reading can be assigned to one of three strata: below 0.5 m, 0.5-1.5 m and above 1.5 m (Fig. D(B)3). These divisions were selected after field trials indicated that they adequately differentiated various shrubland stands that are dominated by the same shrub species, and will give a measure of the vertical distribution of biomass.

Area quadrats are set out along this line to measure tree and herb species. Tree species are measured in quadrats that are 4x10 m. These quadrats are established by placing the 2 m pole at right angles to the line and moving it along the line for 10 m and repeating the process on the other side of the line. Trees, saplings, and seedlings, as defined in Figure D(B)2, are all counted, and the DBH (diameter breast height) of all trees measured, in these quadrats. The values selected to differentiate trees, saplings, and seedlings were based on field observations that "trees" are in the canopy, "saplings" are small trees that are well established but not mature and that "seedlings" are immature individuals not well established.

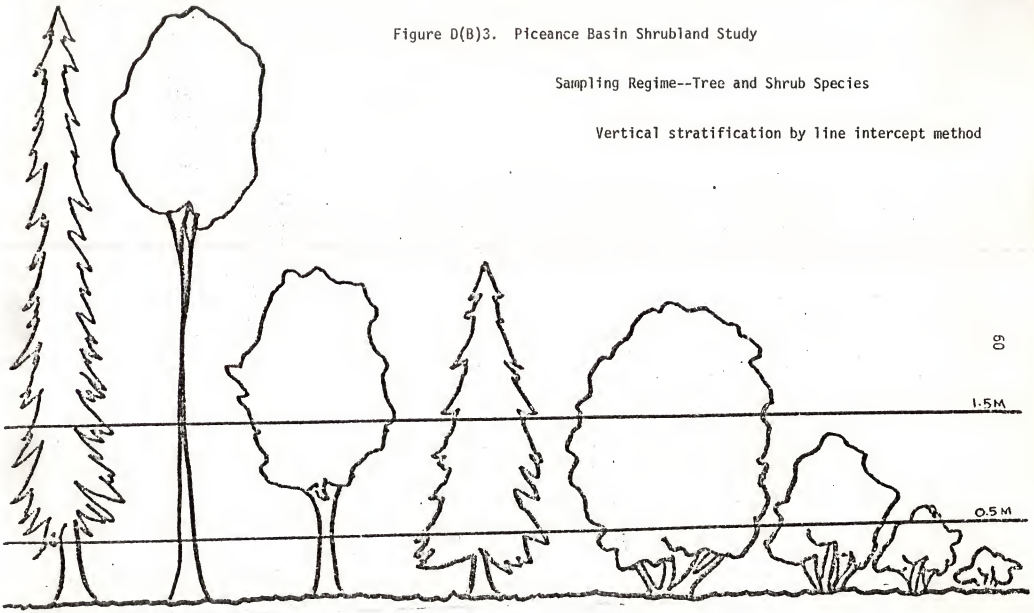
Herbaceous species are sampled in 0.5x1.0 m quadrats placed along the line as illustrated in Figure D(B)2. This will yield frequency data for each species in the understory.

Adequate sample sizes for each method vary greatly from stand to stand, but our tests show that a two man team could complete at least one stand per day in the most difficult types (tall shrublands) and up to four stands per day in the least difficult (low shrublands).

Figure D(B)3. Piceance Basin Shrubland Study

Sampling Regime--Tree and Shrub Species

Vertical stratification by line intercept method



Environmental measurements and estimates are limited to those which can be taken in any stand on any day. No permanent, long term equipment will be installed. The values to be recorded are: slope, exposure, elevation, slope position, parent material, soil depth, soil texture, soil structure (blocky vs. granular), soil color (dark, medium, light) and lime layer (depth). These basic measurements and estimates can be combined into various scalars for further analysis.

Standard methods of gradient analysis will be applied to the data but at this time it is not possible to predict which specific method may be most applicable. Direct gradient analysis methods will be employed as a first approach to analysis and interpretation but, if these prove inadequate, indirect methods will be used.

Discussion

One general goal of these studies is to provide background information on genetic variability enabling reclamationists to address knowledgably the problem of selecting organisms for planting. If an area is to be reclaimed with native species, the question of "What is native?" has to be answered. At one extreme, it may turn out that only small local populations of the desired species can be considered to have the genetic material necessary for successful growth on land to be reclaimed. On the other extreme, perhaps any representatives of a species from a wide geographic range will be adequate to supply propagation material.

There are some biological considerations that address this problem in general. If ecotypic differentiation has taken place within a given species this means that the different populations are differentially adapted to specific environmental situations within the range of the

species. In these instances use of local material for reclamation would be optimal. An exception could occur where a reclaimed environment was so changed that local populations were not fit for it but were more suitable for distant ecotypes. However, such modified situations are unpredictable due to the complexities of ecotypic variation, the underlying selective pressures, and the total interactive milieu of organism with organism and organism with environment. Prudence therefore directs our research toward maximal use of locally evolved and established ecotypes to reclaim situations which are restructured to the pre-reclamation conditions. To put this another way, the experiments of evolutionary processes which result in adapted ecotypes have already been performed. The challenge, then, is to interpret and use the results of these natural "experiments" to the best advantage for reclamation.

SUBPROJECT E

INTERACTION AMONG PLANT SPECIES, SOIL MATERIAL, CULTURAL PRACTICES, AND ENVIRONMENTAL PARAMETERS ON PLANT COMMUNITY ESTABLISHMENT AND RATE AND DIRECTION OF SECONDARY SUCCESSION

PERSONNEL

Dr. C. Terwilliger, Jr., Professor
Mr. David A. Koehler, Research Associate
Mr. Douglas E. Johnson, Graduate Research Assistant

TIME EXPENDED BY CO-INVESTIGATOR FOR CURRENT TERM

Dr. Terwilliger--100% for .5 months

OBJECTIVES

1. To determine the proper reseeding practices for potentially usable plant species and mixtures of plant species and their relationship to cultural practices and inputs.
2. To determine the rate and direction of plant community succession as influenced by: (a) mixtures of species used in revegetation, (b) cultural practices, and (c) soil conditions.
3. To determine allelopathic interaction, if any, which may affect rate and direction of succession.
4. To develop information and guidelines for increasing the successful germination and establishment of important native plants.

PROGRESS TO DATE

Revegetation Technique Plot

At the intensive study site, vegetation was removed from an area totalling approximately 1.9 hectares. Within this area were located six subplots measuring 17x92.5 m. For each test plot, topsoil and subsoil were removed to a 1 m depth by using a 25 cu. meters capacity self-loading scraper aided by a D-8 caterpillar. During the process of ripping and scraping, the earthen material was thoroughly mixed.

Soils from the first subplot were removed, mixed, then stockpiled. Subsequently, soils removed from each successive subplot were replaced in the preceding excavation. When the sixth and final subplot was excavated, the stockpiled material from the initial subplot was utilized to fill it. Since the swell factor of excavated soil material was near zero, no excess material needed to be disposed of. To firm the seedbed, a D-8 caterpillar tractor was "walked" across the plots. This process compacted the loose and dry surface, enabling seeding depth to be more accurately regulated.

Within the six subplots, 24 sub-subplots were located, each measuring 6x8 m. These were separated by a 1.5 m buffer zone and marked with wooden stakes.

The northernmost three subplots will receive supplementary water applications, the remaining three will not. Each of the 24 separate units within the subplots was subjected to three additional levels of treatment. The combinations of the various treatments and the configuration of the subplots are shown in Figure E1. The treatments indicated were as follows:

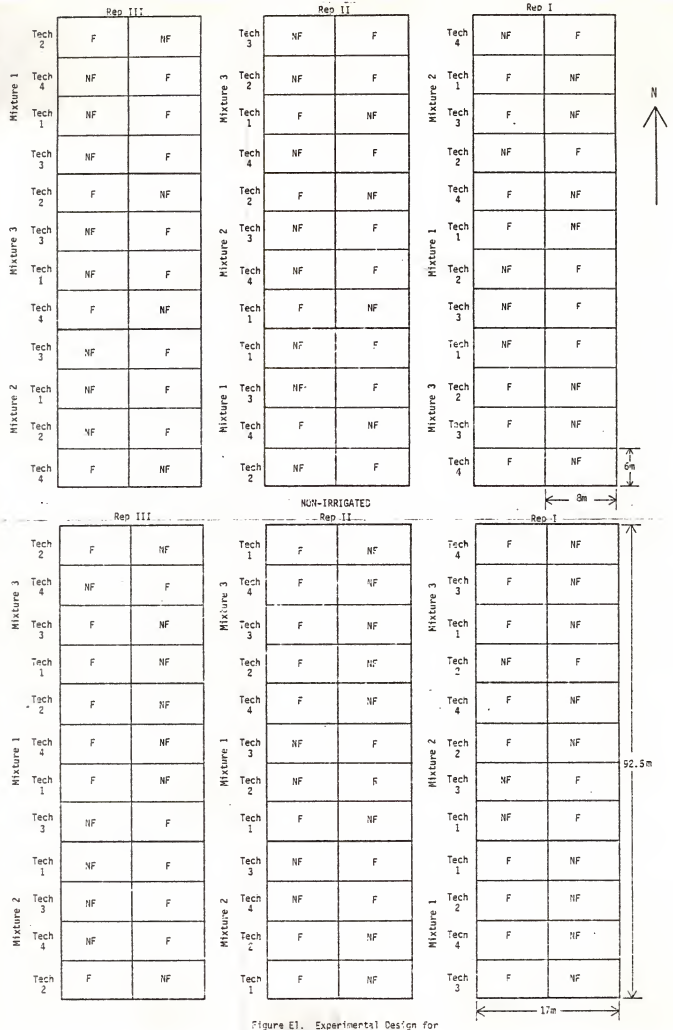


Figure E1. Experimental Design for Revegetation Technique Plot

a. Fertilization

F --fertilized, 100# N, 80# P

NF--non-fertilized

b. Seeding technique

Techinque 1--Drill seed entire mixture, seed grasses and forbs at 1/2 inch and shrubs at 3/4 to 1 inch.

Technique 2--Drill seed entire mixture, seed grasses and forbs at 1/2 inch and shrubs at 3/4 to 1 inch. Decrease seeding rate of grasses and forbs, increase seeding rate on shrubs.

Technique 3--Drill seed grasses and forbs, transplant shrubs following year.

Technique 4--Broadcast seed grasses and forbs, transplant shrubs following year.

c. Seeding mixtures

Mixture 1--Combination, native and introduced species.

1.	Nordan crested wheatgrass	*Agropyron cristatus*
2.	Siberian wheatgrass	*A. sibiricum*
3.	Critana thickspike wheatgrass	*A. dasystachyum*
4.	Sodar streambank wheatgrass	*A. riparium*
5.	Slender wheatgrass	*A. trachycaulum*
6.	Regar meadow brome	*Bromus erectus*
7.	Indian ricegrass	*Oryzopsis hymenoides*
8.	Green needlegrass	*Stipa viridula*
9.	Durar hard fescue	*Festuca ovina duriuscula*
10.	Madrid yellow sweetclover	*Melilotus officinalis*
11.	Utah sweetvetch	*Hedysarum boreale utahensis*
12.	Globemallow	*Sphaeralcea munroana*
13.	Lewis flax	*Linum lewisii*
14.	Arrowleaf balsamroot	*Balsamorhiza sagittata*
15.	Fourwing saltbush	*Atriplex canescens*
16.	Stansbury cliffrose	*Cowania mexicana stansburiana*
17.	Winterfat	*Ceratoides lanata*
18.	Green ephedra	*Ephedra viridis*

Mixture 2--Native species

1.	Rosana western wheatgrass	*Agropyron smithii*
2.	Sodar streambank wheatgrass	*A. riparium*
3.	Bearded bluebunch wheatgrass	*A. spicatum*
4.	Indian ricegrass	*Oryzopsis hymenoides*
5.	Green needlegrass	*Stipa viridula*
6.	Durar hard fescue	*Festuca ovina duriuscula*
7.	Shermans' big bluegrass	*Poa ampla*
8.	Alkali sacaton	*Sporobolus airoides*
9.	Globemallow	*Sphaeralcea munroana*
10.	Utah sweetvetch	*Hedysarum boreale utahensis*
11.	Palmer penstemon	*Penstemon palmeri*
12.	Stansbury cliffrose	*Cowania mexicana stansburiana*
13.	Green ephedra	*Ephedra viridis*
14.	Fourwing saltbush	*Atriplex canescens*
15.	Winterfat	*Ceratoides lanata*
16.	Antelope bitterbrush	*Purshia tridentata*

Mixture 3--Introduced species

1.	Nordan crested wheatgrass	*Agropyron cristatum*
2.	Siberian wheatgrass	*A. sibiricum*
3.	Jose tall wheatgrass	*A. elongatum*
4.	Luna pubescent wheatgrass	*A. trichophorum*
5.	Oahe intermediate wheatgrass	*A. intermedium*
6.	Manchar smooth brome	*Bromus inermis*
7.	Regar meadow brome	*B. erectus*
8.	Vinal Russian wildrye	*Elymus junceus*
9.	Ladak alfalfa	*Medicago sativa*
10.	Madrid yellow sweetclover	*Melilotus officinalis*
11.	Lutana cicer milkvetch	*Astragalus cicer*
12.	Sainfoin	*Onobrychis viciaefolia*
13.	Bouncing bet	*Saponaria officinalis*
14.	Small burnet	*Sanguisorba minor*
15.	Siberian peashrub	*Caragana arborescens*
16.	Russian olive	*Elaeagnus angustifolia*

Successional Studies

Plots have been established in the intensive study area that will indicate the rate and direction of vegetative succession. Studies on these plots will demonstrate the suitability of various seeded mixtures, fertilizer treatments, and mulch treatments for establishing a stable community of an advanced seral stage. A total area encompassing 2.2 hectares was stripped of vegetation and ripped to a depth of 30 cm.

Some topographic restructuring was necessary to prevent runoff and erosion problems. Soil from the sides was used to raise the center (on a north-south line). After shaping and ripping, the plot was backbladed to smooth the surface.

Within the plot, 108 sub-subplots were situated (Fig. E2). Each measures 9x18 m, with a 1.5 m buffer zone between. Each was marked by 16-inch wooden stakes at the corners. The treatments applied were as follows: mulch and no mulch, three fertilization levels, and six species mixtures--all replicated three times. The first treatment (mulching) was non-random owing to the inability of the hydromulcher to reach the plot center without disturbing outer sub-subplots. The latter two treatments were both randomized. Only the phosphorus fertilizer was applied this fall. It was broadcast on the surface, then rototilled and mixed with the soil to a 30 cm depth so as to be available at the site of root-soil interchange. Nitrogen, which is much less permanent in soil, will be applied in the spring after germination has occurred.

A. Mulching

The mulch treatments consisted of Silvafiber hydro mulch applied at a one ton/acre rate and the unmulched controls.

B. Fertilizer treatments

1. 100 pounds nitrogen, 50 pounds phosphorus per acre
2. 50 pounds nitrogen, 25 pounds phosphorus per acre
3. control (0 pounds nitrogen, 0 pounds phosphorus per acre)

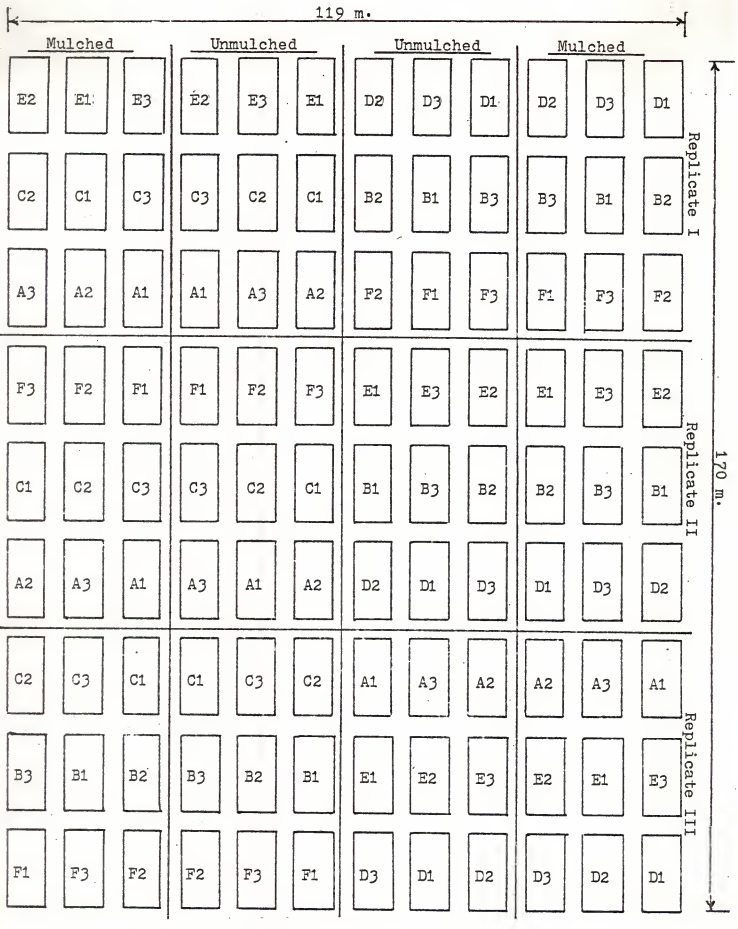

119 m.
170 m.
Mulched
Unmulched
Unmulched
Mulched
Replicate I
Replicate II
Replicate III
E2 E1 E3 E2 E3 E1 D2 D3 D1 D2 D3 D1
C2 C1 C3 C3 C2 C1 B2 B1 B3 B3 B1 B2
A3 A2 A1 A1 A3 A2 F2 F1 F3 F1 F3 F2
F3 F2 F1 F1 F2 F3 E1 E3 E2 E1 E3 E2
C1 C2 C3 C3 C2 C1 B1 B3 B2 B2 B3 B1
A2 A3 A1 A3 A1 A2 D2 D1 D3 D1 D3 D2
C2 C3 C1 C1 C3 C2 A1 A3 A2 A2 A3 A1
B3 B1 B2 B3 B2 B1 E1 E2 E3 E2 E1 E3
F1 F3 F2 F2 F3 F1 D3 D1 D2 D3 D2 D1

Figure E2. Experimental Design for Plant Successional Plot.

C. Seeding mixtures

1. Native grass mixture

	Seeding Rate (PLS)
Wheatgrass, beardless bluebunch	3 lbs/acre
Wheatgrass, western (Rosana)	4 lbs/acre
Needlegrass, green	3 lbs/acre
Ricegrass, Indian	2 lbs/acre
Wheatgrass, streambank (Sodar)	3 lbs/acre

2. Introduced grass mixture

Wheatgrass, crested (Nordan)	3 lbs/acre
Wheatgrass, pubescent (Luna)	4 lbs/acre
Wildrye, Russian (Vinal)	3 lbs/acre
Wheatgrass, intermediate (Oahe)	4 lbs/acre

3. Native grass-forb mixture

Wheatgrass, thickspike (Critana)	3 lbs/acre
Needlegrass, green	2 lbs/acre
Wheatgrass, beardless bluebunch	2 lbs/acre
Ricegrass, Indian	1 lbs/acre
Wheatgrass, streambank (Sodar)	2 lbs/acre
Sweetvetch, Utah	1 lbs/acre
Crownvetch, Emerald	1 lbs/acre
Flax, Lewis	1 lbs/acre
Penstemon, Palmer	1 lbs/acre

4. Introduced grass-forb mixture

Wildrye, Russian (Vinal)	3 lbs/acre
Wheatgrass, crested (Nordan)	3 lbs/acre
Wheatgrass, pubescent (Luna)	3 lbs/acre
Alfalfa (Ladak)	1 lbs/acre
Bouncing-bet	1 lbs/acre
Burnet, small	1 lbs/acre
Milkvetch, Cicer (Lutana)	2 lbs/acre

5. Native grass-forb-shrub mixture

Ricegrass, Indian	2 lbs/acre
Wheatgrass, beardless bluebunch	2 lbs/acre
Wheatgrass, western (Rosana)	3 lbs/acre
Crownvetch emerald	1 lbs/acre
Sweetvetch, Utah	1 lbs/acre
Cliffrose, Stansbury	1 lbs/acre
Ephedra, green	1 lbs/acre
Saltbush, fourwing	2 lbs/acre
Winterfat, common	1 lbs/acre

6. Native and introduced grass-forb-shrub mixture

Needlegrass, green	2 lbs/acre
Wheatgrass, beardless bluebunch	2 lbs/acre
Wheatgrass, crested (Nordan)	2 lbs/acre
Wheatgrass, pubescent (Luna)	2 lbs/acre
Milkvetch, Cicer (Lutana)	1 lbs/acre
Sweetvetch, Utah	1 lbs/acre
Cliffrose, Stansbury	1 lbs/acre
Ephedra, green	2 lbs/acre
Winterfat, common	1 lbs/acre

Annual Disturbance Plot

These are small subplots, measuring 6x9 m, subjected to various degrees of disturbance. No reclamation measures have been implemented. Natural succession and invasion from peripheral plant communities will be the mechanisms dictating which plant species eventually establish there.

Two replications of the following four treatments of increasing severity were constructed (Fig. E3):

(1) Vegetation was removed by scraping with the blade of a caterpillar type tractor. Care was taken to leave as much topsoil as possible.

(2) After removing the vegetation by scraping, the subsoil was ripped and mixed to a 30 cm depth.

(3) After scraping off surface vegetation, a front-end loader was utilized to remove topsoil and subsoil to a 1 m depth. After mixing, the material was replaced in the same area.

(4) After vegetation was scraped off, the top 1 m of topsoil and subsoil was removed and stockpiled. Then, a second 1 m layer of subsoil was removed and stockpiled. The two layers were then replaced in reverse order, with the deeper layer placed on top.

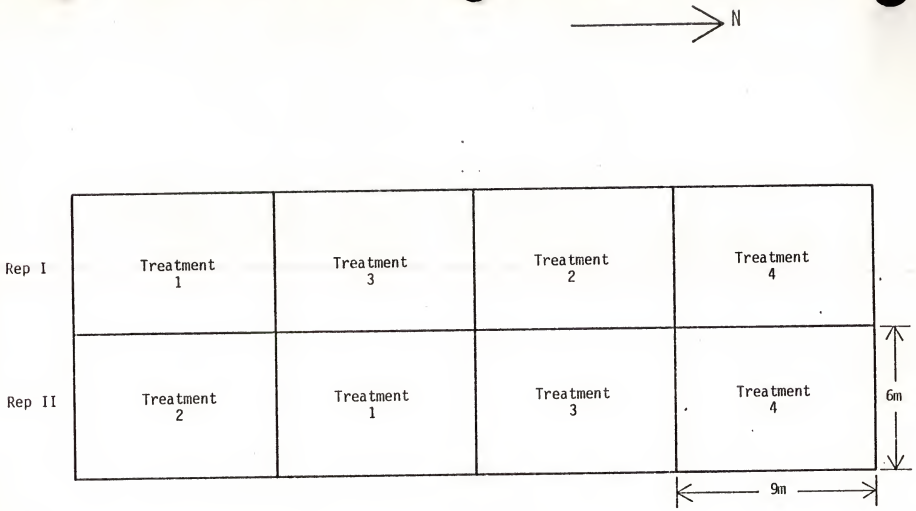


Figure E3. Experimental Design for Annual Disturbance Plot.

SUBPROJECT F

IMPORTANCE OF MYCORRHIZAL FUNGI

PERSONNEL

Dr. F. Brent Reeves, Jr., Associate Professor
Mr. Tom Moorman, Research Assistant
Ms. Jean Kiel, Research Assistant
Mr. David Wagner

TIME EXPENDED BY CO-INVESTIGATOR FOR CURRENT TERM

Dr. Reeves--100% time for 1.5 months

OBJECTIVES

In most natural ecosystems the plants grow in an environment of tremendous microbial activity. Around the roots of plants the most common association is a symbiosis between a fungus and a plant root--a mycorrhiza. Research has demonstrated that the mychorrhizal association benefits the host in both its development and growth. In particular, enhanced uptake of soil elements, particularly phosphorus, increased resistance to drought, and greater biomass of mycorrhizal vs. non-mycorrhizal individuals has been shown for many different plants. For most plants the mycorrhizal association appears to be an absolute rule and non-mycorrhizal plants are the rare exception. However, a few common families of plants typically lack any mycorrhizae, viz. the Cyperaceae, Polygonaceae, Chenopodiaceae, Amaranthaceae, Caryophyllaceae, and Brassicaceae.

In reading the results of Surface Rehabilitation of Land Disturbances Resulting from Oil-Shale Development (Cook, 1974) the observation that most of the plants which invaded the disturbed land were members of the above mentioned non-mycorrhizal families was surprising in view of the fact that most plants are mycorrhizal. Table F1 indicates the most common non-mycorrhizal plants found in the area following disturbance. The abundance of non-mycorrhizal plants which invade disturbed sites in the semi-arid regions of Colorado is in sharp contrast to the results reported for successful plants colonizing mining spoils in the more mesic environments of the east (Pennsylvania) and in Scotland. In fact the suggestion that "mycorrhizal infection may be essential for the survivial of most of the herbaceous plants" was based on the examination of successful plants from Pennsylvanian and Scottish mine spoils.

The hypothesis that delays in the reclamation of disturbed habits to their former relationships may, in part, lie with the mycorrhizal associations was then formulated. The purpose for the initiation of this study was to examine the role of mycorrhizae in secondary succession on disturbed lands in Colorado's oil shale region.

PROGRESS TO DATE

The test of our hypothesis was begun with a survey of the more common plants in the oil shale region to determine which were and which were not mycorrhizal. Our initial objective was to collect the most common plants on both a disturbed and an adjacent undisturbed area near the planned intensive research site. A suitable area was found within Sec. 4, T2S, R98W, only one-quarter mile northeast of the intensive study site. The communities found here were Pinyon-Juniper and Sagebrush. Adjacent

Table F1. Plants occurring on disturbed ecosystems in Colorado's oil shale region.

Low elevation ecosystems--reseeded with Crested wheatgrass (*Agropyron cristatum*)		
1st year	51%	Russian thistle (*Salsola kali*)*
	23%	Crested wheatgrass (*Agropyron cristatum*)
	11%	Indian ricegrass (*Oryzopsis hymenoides*)
8th year	48%	Crested wheatgrass (*Agropyron cristatum*)
	17%	Russian thistle (*Salsola kali*)*
Low elevation ecosystems--not reseeded with Crested wheatgrass		
1st year		Russian thistle (*S. kali*)*
	48%	Lambsquarters (*Chenopodium album*)*
		Miner's candle (*Cryptantha sericea*)
	8%	Native grasses
	34%	Indian ricegrass (*O. hymenoides*)
High elevation ecosystems--reseeded with Crested wheatgrass (but failed to grow)		
1st year	50%	Russian thistle (*S. kali*)*
	22%	Indian ricegrass (*O. hymenoides*)
	12%	Beardless wheatgrass (*Agropyron inerme*)
8th year	15%	Crested wheatgrass (*A. cristatum*)
	9%	Beardless wheatgrass (*A. inerme*)
	40%	Big sagebrush (*Artemisia tridentata*)
		Knotweed (*Polygonum aviculare*)*
	17%	Stickseed (*Lappula redowskii*)
		Dandelion (*Taraxacum officinale*)
Bottomland sagebrush ecosystem--reseeded with Crested wheatgrass		
1st year	99%	Crested wheatgrass (*A. cristatum*)
8th year	24%	Crested wheatgrass (*A. cristatum*)
	10%	Cheatgrass (*Bromus tectorum*)
	43%	Rubber rabbitbush (*Chrysothamnus nauseosus*)
		Greasewood (*Sarcobatus vermiculatus*)*
		Pepperweed (*Lepidium* spp.)*
	prominent	Lambsquarters (*C. album*)
		Stickseed (*L. redowskii*)
Bottomland sagebrush ecosystem--not reseeded with Crested wheatgrass		
1st year	99%	Russian thistle (*S. kali*)*
	1%	Lambsquarters (*C. album*)*

*Indicates genera in families reported to be non-mycorrhizal.

to these communities was an old roadbed which had been disrupted with 30 cm rippers two years earlier. The vegetation on this disturbed site included the species previously reported to invade disturbed sites in this region.

The comparisons of the data from the undisturbed vs. disturbed site indicate that our hypothesis must be studied carefully (Table F2). The complete lack of mycorrhizae on the disturbed site becomes particularly striking when a tabulation of the species sampled shows that 87% of the species in the adjacent undisturbed habit, less than 15 feet away, are mycorrhizal. That 100% of the plants from the disturbed site lack any mycorrhizae strongly supports our hypothesis that conditions for mycorrhizal formation are so altered that the adjacent native plants were unable to reestablish seedlings in the disturbed area.

Further checks on the relative presence of potential mycorrhizal spores in the two soils were designed. A bioassay using corn (*zea mays*) as the test host was employed. Corn was chosen for two basic reasons. One, it has the widest range of any plant known for hosting many different species of mycorrhizal fungi and therefore would serve as a more sensitive indicator. Two, corn has a short life cycle with rapid growth and therefore the experiments would yield results rapidly.

The methods employed in this bioassay were as follows. Pots (10 cm) were sterilized (soaked in 10% Chlorox for 10 minutes and washed) and then filled with a soil-perlite-vermiculite-sand mixture. The perlite, vermiculite, and sand were autoclaved and mixed 1:1:1 (Volume). Soil from either the disturbed or undisturbed site was mixed with the perlite-vermiculite-sand mixture in a 1:3 (Volume) ratio (0.25 in Fig. F1) or in a 0.3:3 (Volume) ratio (0.1 in Fig. F1). Controls were

Table F2. Presence (M+) and absence (M-) of mycorrhizae.

Undisturbed Dump Site		Disturbed Site	
Chenopodiaceae		**Chenopodiaceae**	
Ceratoides lanata	M+	*Atriplex argentea*	M-
Sarcobatus vermiculatus	M-	*A. confertifolia*	M-
		A. rosea	M-
		Chenopodium album	M-
		C. leptophyllum	M-
		Sarcobatus vermiculatus	M-
		Salsola kali	M-
Brassicaceae		**Brassicaceae**	
		Descurania pinnata	M-
		Lepidium perfoliatum	M-
		Physaria acutifolia	M-
Polygonaceae		**Polygonaceae**	
Eriogonum effusum	M+	*Erigonum cernuum*	M-
E. lonchophyllum	M+	*Polygonum aviculare*	M-
Compositae		**Compositae**	
Artemisia tridentata	M+		
Chrysothamnus nauseosus	M+		
Gutierrezia sarothrae	M+		
Haplopappus nuttallii	M+		
Malvaceae		**Malvaceae**	
Sphaeralcea coccinea	M-	*Sphaeralcea coccinea*	M-
Leguminosae			
Astragulus diversifolia	M+		
A. purshii	M+		
Hedysarum boreale	M+		
Rosaceae			
Purshia tridentata	M+		
Polemoniaceae			
Phlox hoodii	M+		
Scrophulariaceae			
Penstemon spp.	M+		

Table F2.--Continued

Gramineae	
Agropyron smithii	M+
A. inerme	M+
Koeleria cristata	M+
Oryzopsis hymenoides	M+
Stipa spp.	M+
Pinaceae	
Pinus edulis	M+
Cupressaceae	
Juniperus utahensis	M+

sterilized soil from both sites mixed at the same ratios. Surface sterilized corn was then planted in these soil mixtures.

The results of these experiments are shown in Figure F1. In only 30 days in both the 0.1 and 0.25 soil mixture from the undisturbed site (U in diagram) the corn was 100% mycorrhizal. However, 60 days were required for corn to become mycorrhizal in the 0.25 soil mixture from the disturbed site, and 90 days were required for mycorrhizae to develop in 0.1 soil mixture from the disturbed site (D in the diagram). The controls remained non-mycorrhizal throughout the experiment.

Our interpretation of these results is that the disturbed soil definitely contains viable mycorrhizal spores but they probably occur in such low numbers that long periods of time are required before infection in the host plant occurs. This delay in infection may account for the delay in the establishment of native plants which are typically mycorrhizal and may require mycorrhizae for survival. Since "ideal" plant establishment conditions with proper temperature and soil moisture conditions are rare or of short duration in arid and semi-arid environments, mycorrhizal limitations may actually be the cause of unsuccessful rehabilitation attempts.

Because current methods of determining relative numbers of mycorrhizal spores and their viability have not been worked out, we chose to sample the saprobic fungi from both the disturbed and undisturbed sites at two depths (6-8 and 18-20 cm) to determine if differences existed in the numbers and kinds of organisms. The procedure used as a standard dilution plate technique using Martin's medium. Our preliminary results are given in Figure F2. As expected, the numbers of saprobic fungi decrease with the increasing depth in the natural, undisturbed ecosystem.

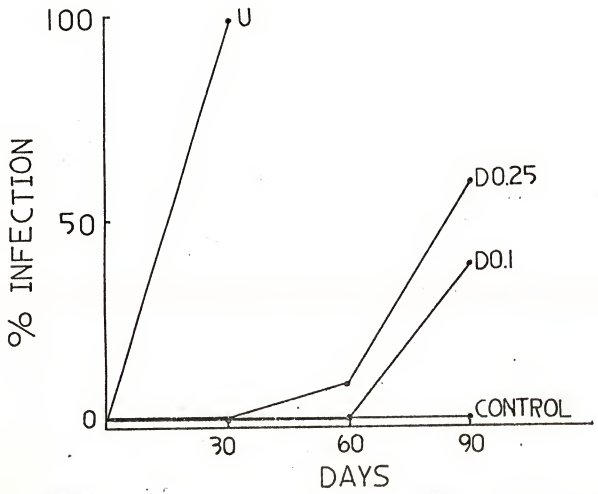


Figure F1. Per Cent Mycorrhizal Infection in Corn Grown in Disturbed (D) and Undisturbed (U) Soil.

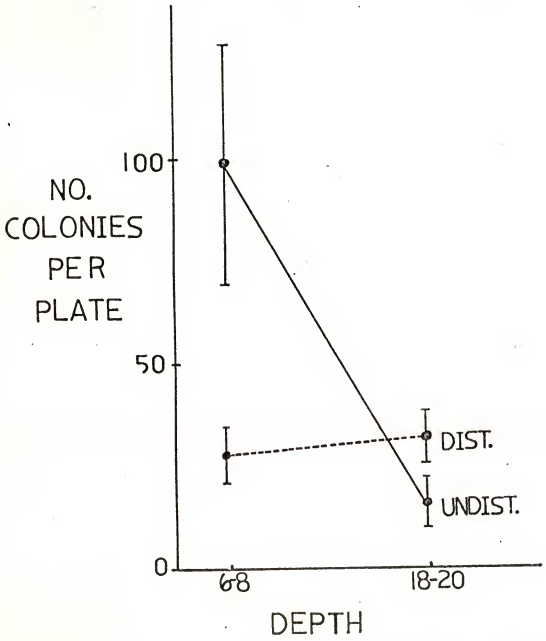


Figure F2. Number of Saprobic Fungi Isolated From Disturbed and Undisturbed Soil

Quite a different situation occurs on the disturbed soil. There appears to be no significant difference in the numbers of saprobic fungi with increasing depth, but we suspect that great variations in species composition occurs. These results must be repeated and checked.

The reduced numbers of saprobic fungi may reflect the situation for the mycorrhizal fungi. In fact, because there is a lack of suitable hosts for the mycorrhizal fungi, their respective numbers may be reduced even more than was observed for the saprobic fungi. The supposed change in species composition in the disturbed habit may also be important in establishing new microbiological relationships with the root environment. Very limited studies elsewhere suggest that in certain cases a change in the microbiological relationships resulting from disturbance may lead to the greater success of potentially parasitic fungi which, in turn, may selectively destroy the seedlings of the native vegetation. At this point this must remain an hypothesis. We have absolutely no data to support this suggestion.

APPENDIX I

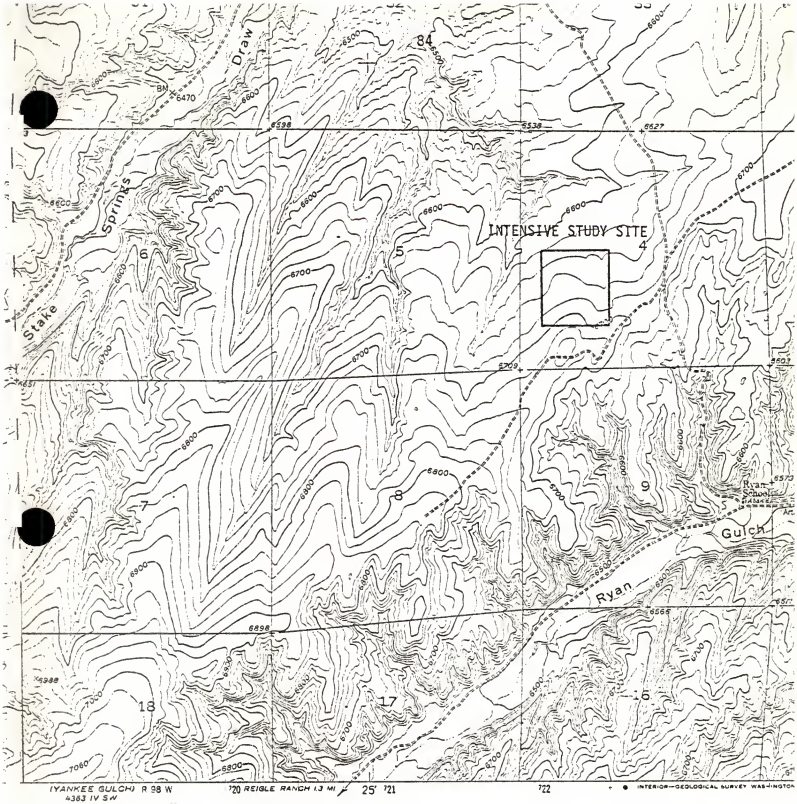


Figure 1. Location of Intensive Study Site

Table 1. List of Species Encountered on the Intensive Study Area in August, 1976

Species	Common Name	Symbol	Sagebrush	Pinyon-Juniper
Agropyron inerme (Scribn. + Smith) Rydb.	Beardless bluebunch wheatgrass	Agin 1	X	X
A. smithii	Bluestem wheatgrass	Agsm	X	X
A. trachycaulum	Slender wheatgrass	Agtr 1	X	X
Bouteloua gracilis	Blue grama	Bogr		X
B. hirsuta	Hairy grama	Bohi		X
Bromus tectorum	Cheatgrass brome	Brte 1	X	
Festuca arizonica	Arizona fescue	Fear 1	X	X
Koeleria cristata	Prairie junegrass	Kocr	X	X
Oryzopsis hymenoides	Indian ricegrass	Orhy	X	X
Poa fendleriana	Mutton bluegrass	Pofe	X	X
P. sandbergii	Sandberg bluegrass	Posa 1	X	X
Sitanion hystrix	Bottlebrush squirreltail	Sihy	X	X
Stipa comata	Needle and thread	Stco 1	X	X
Carex geyeri	Elk sedge	Cage 1	X	X
Antennaria rosea	Greene rose pussytoes	Anro		X
Aster spp.		ASTE	X	X
Astar arenosus	Michaelmas daisy	Asar		X
Astragalus diversifolius	Gray fineleaf astragalus	Asdi		X
A. purshii	Pursh loco	Aspu	X	
Chaenactis alpina	Alpine chaenactis	Chal 1	X	
C. douglasii	Douglas chaenactis	Chdo		X
Chenopodium spp.	Goosefoot	CHEN		X
Cryptantha scricea	Miner's candle	Crse	X	X
Descurainia spp.	Tansy mustard	DESC 1	X	X
Erigeron spp.	Fleabane daisy	ERIG		X
Eriogonum alatum	Wing eriogonum	Eral		X
E. lonchophyllum	Spearleaf eriogonum	Erlo 1		X
Euphorbia fendleriana	Fendler's spurge	Eufe		X
Haplopappus spp.	Goldenweed	HAPL		X
Haploppapus acaulis Nutt.	Stemless goldenweed	Haac	X	X
H. nuttallii	Nuttall goldenweed	Hanu	X	X
Hymenoxys richardsonii	Pingue (do. rubberweed)	Hyri		X
Ipomopsis aggregata	Skyrocket gilia	Ipag	X	
I. congesta	Bullhead gilia	Ipco	X	X
Leptodactylon pungens	Prickly phlox	Lepu		X
Oxytropis lambertii	Cozy weed	Oxla		X
Penstemon spp.	Penstemon	PENS	X	X
P. caespitosus	Mat penstemon	Peca		
Phlox hoodii	Richards hoods phlox	Phho	X	X
P. longifolia Nutt.	Longleaf phlox	Phlo		X
P. multiflora	Flowery phlox	Phmu	X	X
Physaria floribunda	Twinpod	Phfl		X
Senecio multilobatus	Lobeleaf groundsel	Semu		X
Sisymbrium altissimum	L. tumblemustard	Sial		X
Sphaeralcea coccinea	Scarlet globemallow	Spco 1	X	X
Townsendia spp.	Townsendia	TOWN		X
Trifolium gymnocarpon Nutt.	Hollyleaf clover	Trgy	X	X
Artemisia tridentata Nutt.	Big sagebrush	Artr	X	X
Chrysothamnus nauseosus	Rubber rabbitbush	Chna	X	X
C. viscidiflorus Nutt.	Douglas rabbitbush	Chvi 3	X	
Gutierrezia Sarothrae	Broom snakeweed	Gusa	X	X
Juniperus osteosperma	Little Utah juniper	Juos		X
Opuntia fragilis Nutt.	Brittle pricklypear	Opfr	X	X
O. polyacantha	Plains pricklypear	Oppo	X	X
Pinus edulis	Engelm pinyon	Pied		X
Sarcobatus vermiculatus	Black greasewood	Save 2	X	
Tetradymia canescens	Gray horsebrush	Teca	X	X

Table 2. % Frequency in m^2 Quadrats

Species	1	2	3	4	5	6	7	8	9	10	Mean Frequency	11	12	13	14	15	16	17	18	19	20		Grand Mean
Agin 1	40	20			40	40		20	20		18.0										20	2.0	10.0
Agsm									20		2.0		80	100	20	100	20	60	60	80	100	62.0	32.0
Agtr	40	20	60	60	20	80	60	100	40	40	52.0		60			20	20					10.0	31.0
Bogr									20		2.0												1.0
Brte 1											0					20		40	100			16.0	8.0
Fear 1									20		2.0			40		20			20			8.0	5.0
Kocr	20		20		20	20	40	20	60	40	24.0	40	60	60	60	40	20			20	20	32.0	28.0
Orhy	60	60	40	100	40	60	20	20	20	60	48.0	100	40	40	40	60	100	20		60		46.0	47.0
Pafe	20		20								4.0				20				20		20	6.0	5.0
Posa 1	20	40	20				20		40	40	18.0	20	60	100	40	40	60	20	40	60	60	50.0	34.0
Sihy	40		20		20						8.0	60	80		60	40	40	80	80	20	40	50.0	29.0
Stco 1	100	40	60	20	80	40			20	80	44.0	40	40	80	100	80	20		20	80	100	55.0	50.0
Cage 1									20		2.0				20							2.0	2.0
Anro								40			4.0												2.0
ASTE	40		20		20	20		20	60	40	22.0			20	40	20			20	20	40	16.0	19.0
Asdi										60	6.0												3.0
Aspu																20				20		4.0	2.0
Chal 1																		20				2.0	1.0
CHEN	40										4.0												2.0
Crse	100	80	100	60	60	80	40	60	40	20	64.0						40					4.0	34.0
OALE															20							2.0	1.0
OESC					20						4.0							40				4.0	4.0
ERIG	20										2.0												1.0
Eral		20									2.0												1.0
Erlo 1		20									2.0												1.0
Eufe						40					4.0												2.0
HAPL			20								2.0												1.0
Haac				40		20					6.0	20		20								4.0	5.0
Hanu	40	40			20	40	20	20	20	20	22.0	20				20					20	6.0	14.0
Hyri		20									2.0												1.0
Ipaq														20								2.0	1.0
Ipco	20	60	40	80		20	60	40	60	20	40.0	20											2.0
Lepu							20	20			4.0												21.0
Oxla				20						20	4.0												2.0
PENS									20		2.0						20			20		4.0	3.0
Phho	80	40	40	40	40	20	20	20	60	80	44.0	100	80	100	80	80	100			80	60	68.0	56.0
Phlo		40	20	40	20	20					14.0												7.0
Phmu						20	80	20			12.0									20		2.0	7.0
Phfl	20			20		60	40	20		20	18.0												9.0
Semu			60	80	20	40	20	20	60	80	38.0												19.0
Sial					20						2.0												1.0
Spco 1	20								60		8.0		60	40	40		40	20		40	60	30.0	19.0
TOWN							40		40		8.0												4.0
Trgy									20	20	4.0			40	20						20	8.0	6.0
Artr	80	40	40	20	40	60		60	60	40	44.0	80	80	80	100	100	100	100	100	60	100	90.0	67.0
Chna									40		4.0												2.0
Chvl 3																	40					4.0	2.0
Gusa			40		40	40	60	20		60	26.0	20						20		40	20	10.0	18.0
Juos									20	20	4.0												2.0
Opfr	20										2.0						20					2.0	2.0
Oppo									20		2.0							20	60	60		14.0	8.0
Pted										20	2.0												1.0
Teca								20	20		4.0		20		20						40	8.0	6.0

Table 3. Ground Cover in m^2 Quadrats

Species	1	2	3	4	5	6	7	8	9	10	Frequency	11	12	13	14	15	16	17	18	19	20		Grand Mean
Agin	0.6	T			.01	.6		T	.3		.15										.4	.04	.09
Agsm									T		T		1.6	.4	.2	1.01	.2	.2	.4	.5	2.8	.73	.36
Agtr	5.6	.4	.3	3.6	.3	1.7	2	3.8	.6	.6	1.89		.4			.4	1.6					.24	1.06
Bogr									.3		.03												.02
Brte 1																T		T	T				T
Fear 1									.4		.04			.3		.2			T			.05	.04
Kocr	.4		T		T	.2	1.3	T	.4	.3	.26	.3	1	.2	T	.3	.5			T	.4	.27	.26
Orhy	.01	.8	.2	1.01	.4	.3	.3	.01	.9	.01	.39	1.7	.4	T	.4	.9	1.01	T		1.6		.60	.50
Pofe	.01		T								T				T				T		.2	.02	.01
Posa 1	T	T	T				T		T	T	T	T	T	.2	T	T	.4	T	.01	T	T	.06	.03
Sihy	.45		.4		T						.08	.7	.3		.2	.4	.9	1	1.9	T	.3	.57	.32
Stco 1	6.6	1.2	.5	T	2.9	.8			.8	2.3	1.51	.6	1.4	5.4	4.1	1.6	T		T	2.4	2.5	1.80	1.65
Cage 1									.2		.02				T							T	.01
Anro								T			T												
ASIE	T		T		.2	T		T	.01	T	.02			T	T	T			T	T	T	T	.01
Asdi										T	T												T
Aspu																.2				T		.02	.01
Chal 1																		T				T	T
CHEN	T										T												T
Crse	.8	.9	1.3	.4	1.4	.2	.2	1.3	T	T	.65						.5					.05	.35
OALE															.5							.05	.02
OLSC 1					T						T							T				T	T
ERIG	T										T												T
Eral		T									T												T
Erlo 1		.6									.06												.03
Eufe						.01					T												T
HAPL			T								T												T
Haac				1.6		T					.16	T		T								T	.08
Hanu	T	T			T	.4	.2	.4	.01	T	.10	T				T				T	T	T	.05
Hyri		T									T												T
Ipag													.2									.02	.01
Ipco	T	.01	.4	.2		T	.01	.01	.01	T	.06	T										T	.03
Lepu							.2	T			.02												.01
Oxla				.2						.6	.08												.04
PENS									T		T						T			T		T	T
Phho	.3	.8	.8	.8	2	1.4	.5	.2	.4	1	.82	2.9	1.7	2.9	1.7	.2	4.4			2.6	1.5	1.79	1.30
Phlo		1.3	.2	T	.2	T					.17												.08
Phmu						.01	.9	.01			.09									T		T	.04
Phil	T			T		T	T	T		.01	T												T
Semu			.2	T	.01	.01	T	.01	.01	T	.02												.01
Sial					T						T												T
Spco 1	T								.7		.07		.01	T	T		T	T		T	T	T	.04
TOWN							.7		.01		.07			T	T						T		.04
Trgy									T	T	T											T	T
Artr	22.6	6.6	14	6	5	10.6		21.2	6.6	7.6	10.02	17.4	18.8	9.8	19.6	32.2	41	23.8	34	6.4	12.2	21.52	15.77
									2		.2												
Chra																	.6					.06	.03
Chvi 3																							
Gusa			.4		T	.8	T	.01		T	.12	.8						.2		.2	.4	.16	.14
Juos									T	12	1.20												.60
Opir	T										T						T					T	T
Oypo									.6		.06							.4	2	.6		.3	.18
Pied										1.8	.18												.09
Teca								.2	T		.02		.2		T						.2	.04	.03

Table 4. Biomass in Pinyon-Juniper Community
1/10 m quadrats (100 samples)

Species	Green/Weight kg/ka	Dry Weight kg/ka	% Total Biomass	Frequency
GRASSES				
Agropyron smithii	9.5	6.8	1.8	8.0%
A. spicatum inerme	11.0	6.8	1.8	2.0%
A. trachycaulum	59.5	30.3	8.0	25.0%
Koeleria cristata	15.5	11.9	3.1	11.0%
Oryzopsis hymenoides	15.5	12.1	3.2	9.0%
Poa secunda	6.0	(5.0)*	1.3	6.0%
Stipa comata	74.0	51.8	13.7	27.0%
FORBS				
Arenaria fendleri	2.5	2.0	0.5	4.0%
Astragalus diversifolius	1.0	(0.8)*	0.2	1.0%
Cryptantha sericea	30.0	24.0	6.3	30.0%
Eriogonum alatum	2.0	(1.6)*	0.4	1.0%
Erigeron eatonii	0.5	(0.4)*	0.1	1.0%
Euphorbia fendleri	1.5	0.9	0.2	3.0%
Haplopappus acaulis	18.5	16.5	4.4	4.0%
H. nuttallii	19.0	10.6	2.8	12.0%
Ipomopsis congesta	6.5	3.4	0.9	5.0%
Phlox hoodii	17.0	15.3	4.0	17.0%
P. longifolia	6.5	(5.0)*	1.3	11.0%
P. multiflora	4.0	(2.5)*	0.7	3.0%
Physaria floribunda	3.0	(2.0)*	0.5	5.0%
Senecio multilobatus	16.5	11.2	3.0	16.0%
Townsendia incana	1.5	1.0	0.3	3.0%
SHRUBS				
Artemisia tridentata	233.0	111.8	29.5	15.0%
Chrysothamnus viscidiflorus	8.0	4.6	1.2	4.0%
Opuntia polyacantha	146.0	32.1	8.5	3.0%
Tetradymia canescens	13.0	8.2	2.1	1.0%

Table 5. Biomass in Sagebrush Community -- mid-August, 1976
1/10 m quadrats (200 samples)

Species	Green/Weight kg/ka	Dry Weight kg/ka	% Total Biomass	Frequency
GRASSES				
Agropyron smithii	91.25	65.7	11.12	52.5%
A. spicatum inerme	3.25	2.0	0.3	2.0%
A. trachycaulum	14.75	7.5	1.3	4.0%
Bouteloua gracilis	0.25	(0.1)*	0.0	0.5%
Bromus tectorum	0.25	(0.2)*	0.0	0.5%
Festuca arizonica	3.50	(2.0)*	0.3	2.0%
Koeleria cristata	8.25	6.4	1.1	6.5%
Oryzopsis hymenoides	32.00	25.00	4.2	13.5%
Poa fendleriana	0.50	(0.3)*	0.0	0.5%
P. secunda	10.50	(8.0)*	1.4	17.5%
Sitanion hystrix	9.50	(6.5)*	1.1	8.5%
Stipa comata	61.25	42.9	7.3	36.0%
FORBS				
[illegible]enaria fendleri	0.25	0.2	0.0	0.5%
[illegible]haenactis douglasii	0.25	(0.1)*	0.0	0.5%
Cryptantha sericea	1.75	1.4	0.2	2.5%
Erigeron eatonii	4.75	(3.5)*	0.6	7.5%
Eriogonum alatum	1.00	(0.6)*	0.1	0.5%
Haplopappus acaulus	0.50	0.3	0.0	0.5%
H. ruttallii	5.50	3.1	0.5	1.5%
Ipomopsis congesta	0.25	0.1	0.0	0.5%
Linum lewisii	0.50	(0.4)*	0.1	0.5%
Oxytropis lambertii	6.00	2.8	0.5	0.5%
Phlox hoodii	37.75	34.0	5.8	31.0%
P. longifolia	3.00	(2.3)*	0.4	5.5%
Physaria floribunda	0.25	(0.1)*	0.0	0.5%
Senecio multilobatus	0.25	0.2	0.0	0.5%
Sphaeralcea coccinea	11.00	5.2	0.9	10.5%
Trifolium gymnocarpon	0.25	(0.1)*	0.0	0.5%
SHRUBS				
Artemisia tridentata	543.25	277.1	46.9	44.0%
Chrysothamnus viscidiflorus	32.75	19.0	3.2	6.5%
Eurotia (Ceratoides) lanata	5.75	3.5	0.6	1.5%
Opuntia polyacantha	249.00	54.8	9.3	2.5%
Sarcobatus vermiculatus	43.00	12.9	2.2	1.5%
[illegible]tradymia canescens	3.50	2.2	0.4	1.0%

Table 6. Line Intercept Data
30 m Transects

Pinyon-Juniper Community

Transect No.	Species	Total Intercept	% Cover
1	*Artemisia tridentata*	8.07 m	26.9%
	Chrysothamnus nauseosus	0.19	0.6
	Eurotia (Ceratoides) lanata	0.16	0.5
	Juniperus osteosperma	6.85	22.8
2	*Artemisia tridentata*	0.50	1.7
	Juniperus osteosperma	0.80	2.7
	Pinus edulis	11.19	37.3
3	*Artemisia tridentata*	11.54	38.5
	Juniperus osteosperma	8.23	27.4
	Pinus edulis	2.73	9.1
4	*Artemisia tridentata*	1.62	5.4
	Juniperus osteosperma	6.79	22.6
5	*Artemisia tridentata*	3.58	11.9
	Juniperus osteosperma	6.57	21.9
6	*Artemisia tridentata*	4.82	16.1
	Juniperus osteosperma	8.24	27.5
7	*Juniperus osteosperma*	4.89	16.3
8	*Artemisia tridentata*	4.59	15.3
	Juniperus osteosperma	11.03	36.8
9	*Artemisia tridentata*	3.92	13.1
	Chrysothamnus nauseosus	0.32	1.1
	Juniperus osteosperma	1.36	4.5
	Pinus edulis	2.18	7.3
10	*Artemisia tridentata*	1.18	3.9
	Juniperus osteosperma	4.41	14.7
	Pinus edulis	3.73	12.4

Summary of Pinyon-Juniper Line Intercept Data

Species	Total Intercept	Mean Intercept	Mean % Cover
Artemisia tridentata	39.82	3.98	13.3
Chrysothamnus nauseosus	0.32	0.03	0.1
C. viscidiflorus	0.19	0.02	0.1
Eurotia (Ceratoides) lanata	0.16	0.02	0.1
Juniperus osteosperma	59.17	5.92	19.7
Pinus edulis	19.83	1.98	6.6
Totals	119.49	11.95	39.9

Table 6. (Continued)

Sagebrush Community

Transact No.	Species	Total Intercept	% Cover
11	*Artemisia tridentata*	5.21 m	17.4%
	Chrysothamnus nauseosus	1.08	3.6
	Gutierrezia (Xanthocephalum) sarothrae	0.14	0.5
12	*Artemisia tridentata*	6.49	21.6
13	*Artemisia tridentata*	5.95	19.8
14	*Artemisia tridentata*	5.58	18.6
	Chrysothamnus viscidiflorus	0.19	0.6
	Tetradymia canescens	0.13	0.4
15	*Artemisia tridentata*	8.82	29.4
16	*Artemisia tridentata*	7.27	24.2
17	*Artemisia tridentata*	9.86	32.9
18	*Artemisia tridentata*	11.91	39.7
19	*Artemisia tridentata*	5.53	18.4
20	*Artemisia tridentata*	3.31	11.0
	Gutierrezia (Xanthocephalum) sarothrae	0.21	0.7
	Sarcobatus vermiculatus	0.29	1.0

Summary of Sagebrush Line Intercept Data

	Total Intercept	Mean Intercept	Mean % Cover
Artemisia tridentata	69.93	6.99	23.3
Chrysothamnus nauseosus	1.08	0.11	0.4
C. viscidiflorus	0.19	0.02	0.1
Gutierrezia sarothrae	0.35	0.03	0.1
Sarcobatus vermiculatus	0.29	0.03	0.1
Tetradymia canescens	0.14	0.01	--
Totals	71.98	7.19	24.0

TABLE 7
COLORADO STATE UNIVERSITY
SOIL TESTING LABORATORY
SOIL REPORT

Lab. No.	Sample No.	pH Saturated Paste	Cond.	O. M.	NO_3-N	$NaHCO_3$ P	NH_4-AC K	Zn	Fe	Lime	Texture	Cu	Mn
			mmhos/cm	%	ppm	ppm	ppm	ppm	ppm				
1421	Rt.1	8.2	0.4	1.9	6	1	88	0.3	2.3	High	LS	0.32	2.4
1422	Rt.2	7.8	5.6	1.2	5	4	78	0.2	3.0	High	CL	0.42	2.6
1423	Rt.3	8.1	0.5	1.9	6	1	85	0.2	2.2	High	LS	0.36	1.8
1424	Rt.4	8.2	0.5	2.0	6	2	73	0.2	3.1	High	LS	0.58	2.8
1425	Rt.5	8.0	0.7	1.5	5	1	50	0.3	2.7	High	SCL	0.48	2.4
1426	Rt.6	7.8	0.3	1.5	4	2	80	0.3	3.1	High	SL	0.48	2.0

	meq/a - sat. extract Ca	Mg	Na	SAR
1422	26.4	6.9	38.6	9.5

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FORT COLLINS, COLORADO 80523

FEBRUARY 1977

RENEWAL PROPOSAL

RECEIVED
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OFFICE OF
AREA OIL SHALE SUPERVISOR

TO: ENERGY RESEARCH AND DEVELOPMENT ADMINISTRATION

TYPE OF SUPPORT REQUESTED: Research Grant--Renewal Proposal

TITLE OF RESEARCH PROJECT: "Rehabilitation Potential and Practices of Colorado Oil Shale Lands"

PRINCIPAL INVESTIGATOR:
Phillip L. Sims, Ph.D.
Associate Professor
Department of Range Science
Colorado State University
Fort Collins, Colorado 80523
Phone: (303) 491-6541

AMOUNT REQUESTED: $395,249

UNIVERSITY OFFICIAL TO BE CONTACTED REGARDING GRANT OR CONTRACT NEGOTIATION:
M. J. Price
Contracts and Grants Administrator
Office of Sponsored Research
Colorado State University
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ABSTRACT

The attached document is a second year renewal proposal to the original research grant (Contract No. E(11-1)-4018) for the period June 1, 1977 to May 31, 1978. The proposed research is the continuation of a program designed to meet the goal of elucidation of guidelines for the rehabilitation potential and practices of Colorado oil shale lands, as stated in the Proposal Supplement of March 1976.

An Intensive Study Site has been selected and several study sites have been developed. As of this time, substantial progress has been made in the microbiological, plant genetics, and plant community succession subprojects. These accomplishments, however, are in their incipiency. As retorted oil shale material becomes available for additional studies, and as further data from ongoing studies is assimilated, rehabilitation guidelines will continue to be defined. The request for construction of the retorted shale experimental plots were outlined in an earlier transmittal dated February 7, 1977.

The research team assembled to carry out this project is basically the same as found in the March 1976 Proposal Supplement. Changes that have occurred are as follows: Dr. Julius Nagy is now part of Dr. Willard Chappell's research team which is involved in the study of trace elements; Drs. Richard Ward and Ralph Dix are responsible for ecological and genetic investigations for shrubs and forbs; and, finally, Dr. Brent Reeves is responsible for mycorrhizal studies.

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INTRODUCTION

Work proposed for the second year of funding will be a continuation of studies proposed in the March 1976 Proposal Supplement. Most studies have been initiated, but some have only completed preparatory investigations because of the unavailability of retorted oil shale material in 1976.

All subprojects will continue in 1977 except for Subproject A. The Resource Management Unit Handbook is near completion and will be ready for publication by June 1, 1977. Therefore, additional funding for this subproject is not requested.

In order to strengthen the objectives of Subproject E two additional studies have been proposed. The first would initiate research into specific ecological requirements for the germination of seeds of important native plants suitable for reclamation purposes. Those requirements would be determined by a series of growth experiments in a controlled environment. The information obtained from this work will be beneficial to the overall success of revegetation in the Piceance Basin. The second would study the interaction of plant species, and cultural practices on a mixture of TOSCO II and Paraho processed shale. The retorted shale mixture would consist of 65% TOSCO and 35% Gas Combustion Process materials as is proposed in Rio Blanco Oil Shale Project's (RBOSP) Detailed Development Plan for Tract C-a. Both studies would conform to the overall objectives of Section E.

PROJECT MANAGEMENT

Dr. Sims will continue to serve as Principal Investigator and Mr. Edward Redente, Senior Research Associate, will continue to assist him in project management related areas. A full-time secretary is presently employed and will assist the Principal Investigator and Research Associate.

The roles of Project Management personnel will be comparative to the responsibilities outlined in the March 1976 Proposal Supplement. These responsibilities relate to overall project management and coordination, scientific and technical soundness of research, interaction with state and federal agencies, coordination of field research activities, preparation of reports, monitoring progress of activities, and fiscal responsibilities.

The research team has and will continue to have periodic discussions to coordinate objectives, research procedures and interact with scientists working on related projects. One such meeting took place on January 13, 1977 and involved ERDA and EPA funded oil shale investigators from CSU and CU along with representatives from industry, state and federal agencies.

Work Plan

A generalized diagram of the activities of the project is shown in Figure 1. More detailed description of project activities is found in the respective subproject sections. Major plot construction will include the establishment of the nitrogen-phosphorus balance plot and processed shale successional test plots. Construction of these plots will extend through the summer as retorted shale is produced and transported to the Intensive Study Site. Microbiological sampling along with plant ecotypic and selection studies will begin in the spring and extend through the fall season. Vegetation sampling on plots established in 1976 will occur throughout the 1977 growing season.

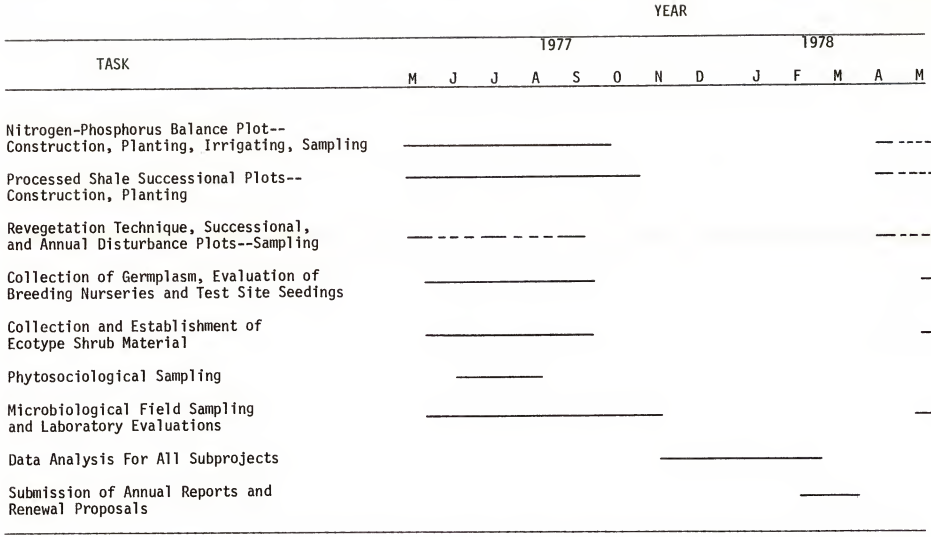

Figure 1. Generalized diagram showing schedule of activities and plan of work (-----preliminary or follow-up study, _____intensive study).

BUDGET SECTION

The Budget Section is divided into two parts. The first section will include Project Management Budget and the second will include the Overall Project Budget. A Supplemental Budget Request was submitted on February 7, 1977 which included major expenditures required for Intensive Study Site development. Therefore, the Project Management Budget included here relates primarily to personnel, publications and travel.

BUDGET

PROJECT MANAGEMENT

A-II (a) REIMBURSABLE PORTION	Year 2
1. SALARIES AND WAGES	
aa. Scientific Discipline Personnel	
* Principal Investigator Phillip L. Sims 100% of time for 2 months @ $2,550 per month	$ 5,100
* Senior Research Associate Edward F. Redente 100% of time for 12 months @ $1300 per month	15,600
bb. Support Personnel	
* Secretarial	8,000
Hourly Labor	5,000
cc. Fringe Benefits	
Public Employees Retirement Association, 10.64% of *	3,054
Total Salaries, Wages and Annuities	36,754
2. INDIRECT COSTS - 64% of salaries, wages, and annuities	23,523
3. PUBLICATIONS AND REPORTS	1,000
4. TRAVEL	
aa. Domestic	
To and from research site	3,000
Scientific meetings	2,500
5. OTHER DIRECT COSTS	
Computer Services	1,500
6. TOTAL DIRECT COSTS	44,754
7. GRAND TOTAL	68,277

OVERALL PROJECT

Total projected cost for the second year is calculated to be $395,249. A total of 129 man-months of scientific discipline personnel are to be devoted to this study during the second year. This includes the principal investigator, 8 co-investigators, 1 post-doctoral assistant, 1 senior research associate, 4 junior research associates, and 9 graduate research assistants. Support personnel will consist of secretarial, research technicians, and hourly labor bringing the total cost for personnel to $182,450. Additional costs are related to supplies and materials, equipment, travel, and indirect costs.

OVERALL PROJECT BUDGET

COLORADO STATE UNIVERSITY
June 1, 1977 to May 31, 1978

A-II (a) REIMBURSABLE PORTION	Year 2
1. SALARIES AND WAGES	
aa. SCIENTIFIC DISCIPLINE PERSONNEL	
*Principal and Co-Investigators 14.5 months	$ 35,635
*Senior Research Associate 12 months @ $1300 per month	15,600
*Junior Research Associates 43.5 months @ $990 per month	43,065
*Post-doctoral Assistant 5 months @ $1100 per month	6,600
9 Graduate Research Assistants, 50% of time @ $4,400 per year	39,600
bb. SUPPORT PERSONNEL	
*Secretarial	8,850
*Research Technician	9,600
Hourly Labor	23,500
cc. FRINGE BENEFITS	
Public Employees Retirement Association 10.64% of *	12,699
PUBLIC EMPLOYEES RETIREMENT ASSOCIATION IS A MANDATORY RETIREMENT PLAN FOR ALL EMPLOYEES OF THE STATE OF COLORADO. AS A RESULT OF RECENT LEGISLATION THE RATE OF CONTRIBUTION IS: 10.64%	
Total Salaries, wages and annuities	195,149

2.	INDIRECT COSTS-64% of Salaries, Wages and Annuities	$ 124,896
	COLORADO STATE UNIVERSITY'S OVERHEAD RATE ON PROPOSALS IS 64% OF SALARIES, WAGES, ANNUITIES, SICK LEAVE, HOLIDAYS AND VACATION. AUDIT WAS PERFORMED AND THE ABOVE PROPOSAL RATE APPROVED BY THE DEPARTMENT OF HEALTH, EDUCATION, AND WELFARE.	
3.	SUPPLIES AND MATERIALS	13,550
**4.	EQUIPMENT	15,755
5.	PUBLICATIONS AND REPORTS	3,800
6.	TRAVEL	
	aa. DOMESTIC	
	To and from research site	21,850
	Scientific Meetings	6,650
7.	OTHER DIRECT COSTS	13,600
8.	TOTAL DIRECT COSTS	270,354
9.	GRAND TOTAL	395,250

**COLORADO STATE UNIVERSITY HEREBY CERTIFIES THAT THE EQUIPMENT REQUESTED FOR PURCHASE (SEE SUBPROJECT BUDGETS) IS NOT REASONABLY AVAILABLE WITHIN THIS INSTITUTION.

A-II (b) ITEMS SIGNIFICANT TO THE PERFORMANCE OF THE PROJECT CONTRIBUTED BY THE UNIVERSITY

None

A-II (c) TIME OF PRINCIPAL INVESTIGATORS CONTRIBUTED BY THE UNIVERSITY

None

INFORMATION CONCERNING INSTITUTION SUBMITTING PROPOSAL

A. This proposal is submitted by COLORADO STATE UNIVERSITY. Contracts and grants that result from this proposal should be made in the name of COLORADO STATE UNIVERSITY.

B. The officials authorized to sign and submit proposals and to negotiate contracts and grants are the following: (1) Harold J. Carroll, (2) Galen E. Frantz, (3) M. J. Price, Contracts and Grants Administrators; and James F. Brown, Director, Office of Sponsored Research

C. Correspondence should be addressed to: COLORADO STATE UNIVERSITY, Fort Collins, Colorado 80523; Attention: Director, Office of Sponsored Research; Telephone: 491-6355; Area Code: 303.

D. The ASSOCIATE VICE PRESIDENT FOR RESEARCH of COLORADO STATE UNIVERSITY, George G. Olson, is authorized to sign contracts or to acknowledge grants.

E. Colorado State University is an agency of the STATE OF COLORADO and enjoys exemption from tort liability.

STATEMENT OF SOLICITING

We hereby certify that we have not employed or retained a company of person (other than a full-time employee) to solicit or secure this contract (grant) and agree to furnish information relating thereto as requested by the Sponsor's cognizant officer.

We certify that the distribution of costs between the direct and indirect categories as shown in the proposal conforms to the usual accounting practices of the institution and to the distribution used by the cognizant federal audit agency.

February 24, 1977
Date

Phillip L. Sims
Dr. Phillip L. Sims
Principal Investigator

C. Wayne Cook
Dr. C. Wayne Cook, Chairman
Department of Range Science

M. J. Price
M. J. Price
Contracts and Grants Administrator

SUBPROJECT B

TITLE: LONG-TERM FERTILITY MAINTENANCE ON LAND DRASTICALLY DISTURBED BY OIL SHALE DEVELOPMENT

PERSONNEL: Dr. William A. Berg, Associate Professor
Dr. Burns A. Sabey, Professor

OBJECTIVES

Long-term fertility requirements and methods of meeting these requirements on deficient soil materials disturbed by oil shale development in northwestern Colorado will be determined.

CONTINUATION PROPOSAL

The following treatments represent the experimental approach to the problem of supplying adequate N and P for vegetation established on the extremely deficient soil materials at the intensive study site:

1. Low to moderate annual applications of inorganic fertilizer N over a four-year period. The annual per-hectare rates are:
   a. 56 kg N
   b. 112 kg N
   c. 224 kg N
   d. 448 kg N

2. High rates of inorganic fertilizer N added only at the initiation of the study. These rates give a total N treatment equal to the summation of the four annual applications in treatment 1. The per-hectare rates are:
   a. 224 kg N
   b. 448 kg N
   c. 896 kg N
   d. 1793 kg N

3. The high N fertilizer rates as in treatment 2 above, plus sawdust

added at the initiation of the study at a rate of (a) 11.2, (b) 22.4, (c) 44.8, and (d) 89.7 metric tons per hectare, respectively.

4. Moderate to high rates of sewage sludge and sawdust added at the initiation of the study. The per-hectare rates on a dry weight basis are:
   a. 56 metric tons sludge
   b. 112 metric tons sludge + 22.4 metric tons sawdust
   c. 224 metric tons sludge + 44.8 metric tons sawdust
5. Phosphorus applications with nitrogen:
   a. 112 kg N/ha + 112 kg P_2O_5 (48 kg P)/ha
   b. 896 kg N/ha + 112 kg P_2O_5 (48 kg P)/ha
   c. 112 kg N/ha + 448 kg P_2O_5 (192 kg P)/ha
   d. 896 kg N/ha + 448 kg P_2O_5 (192 kg P)/ha
6. A check plot receiving no N fertilizer.

These give a total of 20 treatments. The smallest feasible plot size is 4.5 x 9 meters. This should result in an effective plot of about 3 x 7.6 meters when border effects from adjacent treatments are considered. Thus, an area of 836 sq. meters will be needed for one set of treatments. Three replications will be used for a total area requirement of 2,508 sq. meters.

The study will be established on N-deficient soil materials. The climatic regime and elevation at the site is typical of much of the land that may be disturbed by oil shale development.

Earth-moving equipment will be needed to level exposed subsoil or alluvial materials on the site. The site will be worked with a heavy duty rototiller. A sprinkler-irrigation system will be used to establish uniform vegetation stands. This will require a total of about 38 cm of water (1-1/3 acre feet) during the two months after seeding.

A uniform application of P will be broadcast over the N-only plot area and worked in. The rate should be high enough so that there is no plant growth response to the P in the manure or sewage sludge. A rate of 672.5 kg triple superphosphate per hectare should achieve this. The inorganic N fertilizer will be ammonium nitrate, which will be broadcast and then worked into the soil.

Species seeded will be a mixture native to the area, similar to the mixtures used by Harbert and Berg (1974). The work of Sims and Redente (1974) serves as a guide to individual species adapted to the area. Drilling is the seeding method to be used. The area will be mulched with wheat straw at the rate of 4.5 metric tons per hectare, the straw will be crimped into the soil by use of a disc.

Stand counts will be made 30 and 60 days following seeding. Thereafter, stand counts will be made annually in mid-June. Ground cover by living and dead vegetation will be estimated in March and June of each year. Estimates of forage production will also be made. Small quadrats will be clipped for dry matter production and N analysis.

Surface soils in each treatment will be sampled annually to a depth of 15 cm. Plant available phosphorus, nitrate-N, total N, and soluble salts will be determined on the soil samples. Nitrogen will also be determined in samples of the organic wastes so that an overall estimate of the N balance can be made for each treatment. It is thought that in this climatic zone little, if any, N will be leached below plant root depths by natural precipitation. Some N loss to the atmosphere from the sludge is expected.

LITERATURE CITED

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Sims, P. L. and E. R. Redente. 1974. Revegetation of disturbed surface soils in various vegetation ecosystems in the Piceance Basin. Colo. State University Environmental Resources Center Technical Report 5. 157 p.

BUDGET
SUBPROJECT B

		Year 2
1.	SALARIES AND WAGES	
	aa. Scientific Discipline Personnel	
	* Co-Investigator B. R. Sabey 100% of time for 1 month	$ 2,200
	* Co-Investigator W. A. Berg 100% of time for 1 month	2,200
	Graduate Research Assistant 50% of time for 12 months	4,400
	bb. Support Personnel	
	* Research Technician	5,600
	Hourly Labor	2,500
	cc. Fringe Benefits	
	Public Employees Retirement Association 10.64% of *	1,064
	Total salaries, wages and annuities	17,964
2.	INDIRECT COSTS	
	64% of salaries, wages, and annuities	11,497
3.	SUPPLIES AND MATERIALS	
	Organic wastes	1,500
	Chemical fertilizer	300
	Seed	300
	Mulch	500
4.	EQUIPMENT	
	Spectrophotometer	2,000
5.	PUBLICATIONS AND REPORTS	200
6.	TRAVEL	
	Domestic (to and from site)	5,000
	Scientific meetings	500

7. OTHER DIRECT COSTS	
Lab supplies	1,000
Lab analysis	3,000
Tractor rental	1,000
8. TOTAL DIRECT COSTS	33,264
9. TOTAL SUBPROJECT COSTS	44,761

SUBPROJECT C

TITLE: THE ROLE OF SOIL MICROORGANISMS AS INDICATORS AND POSSIBLE CONTROLLING FACTORS IN PLANT SUCCESSION PROCESSES ON DISTURBED SOILS

PERSONNEL: Dr. Donald A. Klein, Associate Professor
Dr. James P. Nakas, Research Associate
Nicholas Nagle, Research Technician
Linda Smith, Research Assistant

OBJECTIVES

The objectives of the subproject are to determine the possible responses and changes in non-mycorrhizal soil microorganisms during the reestablishment of plant materials based, when possible, on considerations of the effects of the plant root environment on microbial activities.

CONTINUATION PROPOSAL

Phase I

To evaluate microbial responses and changes in numbers and activity during re-establishment of plant communities on disturbed soils.

For this period, the various revegetation plots at the intensive study site installed during the late fall of 1976 will be used. These include the successional, revegetation technique, and annual disturbance plots. When the spent shale successional plot installation is completed during the summer of 1977, this will be included in the test series.

Job 1-1: Evaluation of soil microbial populations and activities in relation to plant succession.

The following parameters will be followed, as noted in the original proposal for the first year of work:

- Total soil bacteria and actinomycetes using sodium caseinate agar (Anonymous, 1968).
- Fungi, using Rose Bengal Medium (Martin, 1950).
- Nitrification activity, using an ammonium ion-mineral salt solution

added to 40 g portions of soil, followed by analysis for nitrate production of varied incubation times (Aaronson, 1970).

- Nitrogen levels (NO_3).
- Phosphorus levels (inorganic).

The N and P assays will be carried out by cooperating scientists working on related subprojects.

- Dehydrogenase activity using the procedure of Klein, Loh and Goulding (1971).
- Phosphatase activity, using the procedure of Tabatabai and Bremner (1969).
- Fungal versus bacterial contributions to decomposition processes, using procedures of Harrison, Wright and Morita (1970) and Anderson and Domsch (1973).

Job 1-2: Evaluation of plant-associated microbial activities in relation and succession processes.

In comparison with the all-over soil analysis which will be completed under Job 1-1, the work in this phase will be concentrated on the microbial populations which are present on the surface of plant roots, which may more closely reflect plant-related changes in microbial populations and activities. Analysis of the rhizosphere zone microbes of major plants which are being considered for the site will be carried out, including the following:

- Grasses (a) Agropyron smithii, Western wheatgrass
  (b) Oryzopsis hymenoides, Indian ricegrass
  (c) Poa pratensis and hybrids, Kentucky and other bluegrass
  (d) Festuca ovina and F. ovina duriuscula, sheep and hard fescue
- Legumes (a) Lupinus alpestris etc., native lupine

(b) Hedysarum boreale utahensis, Utah sweetvetch

(c) Astragalus cicer, cicer milkvetch

In the rhizosphere, nitrifier populations will be enumerated for selected plants by a MPN Technique (Pramer and Schmidt, 1964; Alexander and Clark, 1965).

The extent of mycorrhizal colonization will be determined using procedures of Klein and Molise (1975), if necessary to supplement the mycorrhizal subproject effort. The goal of the work will be to determine if there are any correlations between inorganic phosphorus availability dynamics and mycorrhizal colonization of grasses with various management techniques.

Job 1-3: Plant microbe relationships--initial survey phases of succession changes in soil characteristics as related to microbial activities.

For this phase of the work, which will be carried out in the early summer of 1978, soil samples taken from the test areas used in Jobs 1-1 and 1-2 will be extracted, using distilled water and ethanol as described by Newman and Norman (1943) and the extracts will be used to determine possible effects on the following processes under standardized laboratory conditions:

- Nitrification, using procedures of Moore and Waid (1971) and Neal (1969).
- Respiration, using a mixed soil inoculum grown on soil extract broth and measuring oxygen utilization in a YSI oxygen probe system (Wu and Klein, 1976).
- Nitrogen fixation, a standard reference soil from the test site will be tested for acetylene reduction capability using distilled water or the desired soil extract by procedures described by Hardy, et. al. (1968).

Phase II

Development of approaches for controlling or modifying plant-microbe interactions to enhance or control the succession process. This work will be initiated in the spring 1978 period.

Based on the available background literature, as summarized by Rice (1974), it appears that plants may cause changes in soil microbiological processes such as nitrification and nitrogen fixation, which may play essential roles in succession processes. The purpose of this work, which will extend into the third year of the project, will be to provide management-related information on these processes.

Job 2-1: Microbiological characteristics of plants representative of succession and climax stages being considered for use in the test plot systems. Major plants which are components of plant mixtures as developed by Dr. Terwilliger in the allelopathy portion of the study will be examined for the following parameters:

- Microbial populations and possible differences between plant types using previously-described cultured techniques.
- Effects of water and ethanol extracts of soil from the various test plants on nitrification activities of standard soil microbial populations.
- Nitrogen fixation activities in the rhizosphere will be assayed using techniques given in Job 1-3.

Job 2-2: Plant material decomposition studies.

Portions of plants from varied successional stages will be allowed to decompose in samples of a standard test soil, to determine if inhibitors of the processes of nitrification, respiration or nitrogen fixation might be

produced or released by specific plant materials.

In both 2-1 and 2-2, water will be passed through containers containing soil and the decomposing plant material samples at bi-weekly intervals and collected for subsequent testing of possible effects on nitrification and nitrogen fixation of standard microbial populations.

Job 2-3: Effects of physical disturbance on the ability of reference climax community soils to influence microbiological activities (only if time permits will work in this area be initiated before May 30, 1978).

If reference or climax soils are found to possess an ability to influence nitrification, respiration or nitrogen fixation, processes, the effects of various types of physical disturbance on these microbiological characteristics of soils will be studied.

Among the physical disturbances which will be tested are the following:

- Sieving to remove plants
- Drying at room temperature or at 55-60^0 C, which might occur with surface soils.
- Periodic wetting and drying of soils on a semi-weekly basis.
- Water saturation of soils.

These tests will be carried out with the assumption that a clearly measurable ability of the climax community soil to influence microbial activities had been detected in the Phase I studies. Based on the previous literature as summarized by Rice (1974) it should be possible to identify a sensitive factor amenable to further study.

Additional Possible Work

If required during the spring of 1978, cooperative soil samplings will be made to coordinate with the research program of Dr. Wildung of Batelle

Northwest, related to analyses of hydrocarbon decomposition products and metal-microbe interactions in spent shale materials. As work has been carried out in the areas of hydrocarbon degradation and metal-microbe interactions in this laboratory such sampling and analysis coordination will complement both of these programs by maximizing data comparability.

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BUDGET
SUBPROJECT C

	Year 2
1. SALARIES AND WAGES	
aa. Scientific Discipline Personnel	
*Co-Investigator D. A. Klein 100% of time for 2½ months @ $2,600/month	$ 6,500
*Post-doctoral Assistant 50% of time for 12 months @ $550/month	6,600
Graduate Research Assistant 50% of time for 12 months	4,400
bb. Support Personnel	
*Technician ½ time	4,000
1 hourly Assistant	2,000
cc. Fringe Benefits	
Public Employees Retirement Association 10.64% of *	1,819
Total salaries, wages and annuities	25,319
2. INDIRECT COSTS	
64% of salaries, wages and annuities	16,204
3. SUPPLIES AND MATERIALS	
Significant Items of a Special Nature:	
Radiotracer materials	500
Scintillation Supplies	400
Other supplies:	
Routine glassware	500
General chemicals	800
Media	900
4. EQUIPMENT	
In excess of $1,000:	
Digital pH Meter--Northrup (for use in nitrate determination)	1,300
Other equipment:	
Lab-Top Shaker	600
Replacement Nitrate electrodes (2 sets)	600
Misc. equipment repair parts	605

5. PUBLICATIONS	300
6. TRAVEL	
Domestic (to and from research site)	850
Scientific meetings	1,050
7. OTHER DIRECT COSTS	
Greenhouse expenses	500
8. TOTAL DIRECT COSTS	34,224
9. TOTAL PROJECT COSTS	50,428

SUBPROJECT D(A)

TITLE: SELECTIVE BREEDING OF GRASSES, LEGUMES, AND FORBS TO DEVELOP IMPROVED STRAINS THAT CAN BE ESTABLISHED ON DISTURBED SITES IN OIL SHALE AREAS TO PRODUCE A STABILIZED ECOLOGICAL COMMUNITY.

PERSONNEL: Dr. Robin Cuany, Associate Professor
Mr. Walter Padilla, Research Assistant

OBJECTIVES

Research on selection and breeding of plant materials is programmed along the lines of the five objectives as stated in the original proposal:

1) To collect and assemble germplasm sources
2) Evaluation of spaced plants in two nurseries, and clonal propagules or progenies under controlled stress - salinity.
3) Evaluation of seeded progenies in intensive site and satellite field plantings
4) To use suitable breeding procedures for recombination and progeny testing to develop improved strains
5) To coordinate research on best means of multiplying and planting improved strains.

Certain items which it was not possible to explore in the first budget year will receive new emphasis. Additional personnel to be added for the next project year will enable us to study a more reasonable number of species to meet the above five objectives.

CONTINUATION PROPOSAL:

1. Germplasm sources

The major collecting of ecologically relevant sites has already been done for western wheatgrass and Indian ricegrass; therefore, collecting of grasses will emphasize one or two types of fine-leaved fescues of the Festuca ovina--arizonica-idahoensis group. Some accessions will be local collections and some

will be sought by correspondence, and likewise for usable strains of Poa pratensis or its interspecific crosses studied at the Carnegie Institution of Washington, Stanford, California.

For the legumes, our collecting will emphasize the native lupines below 2,286 meters and several locations for Utah sweetvetch, so as to cover the range of genecological variation for both these species. We will continue to receive breeding lines of the introduced species Astragalus cicer from the USDA-ARS.

Initiation of systematic collection of other forbs will start for two or three species from among the genera Balsamorhiza, Osmorhiza, Penstemon or Sphaeralcea. The precise choice will be made in light of data from existing trial plots and the ecology of disturbed areas, with attention to relative status of their mycorrhizal associations.

2. Maintenance and evaluation of breeding nurseries

Four existing nurseries of Agropyron smithii (two each at Fort Collins and Meeker) and two of Oryzopsis hymenoides will be maintained for type observation and growth habit comparison, including vigor and vegetative spread. Genetic variability measured within versus among sources is used to calculate heritability of various characters, and the seed and vegetative propagules from desirable plants are used as parent stock for breeding advancement, parallel with or subsequent to individual-plant progeny tests of various kinds. Screening of progeny for germination under salinity stress will continue, and promises the chance of breeding wheatgrass or ricegrass strains with higher salinity tolerance, as may be needed for effective rehabilitation of retorted oil shale and some disturbed soils.

Vegetative material from these nurseries will be supplied to the sub-projects on microbial decomposition and mycorrhizal relationships. Seed harvests in 1977 from the newer nurseries will be needed for objective 3 (below).

We expect also to make a feasibility test on establishing western wheatgrass in critical areas by planting sprigs rather than sowing seed.

New nurseries will be initiated for lupines, Utah sweetvetch, other forbs, and possibly fine-leaf fescues, in Summer 1977. Some of these nurseries would have to be delayed until Spring 1978 if either the external source or the collection date make 1977 planting impossible. The nitrogen-fixing status of currently available sources (in the greenhouse) or forthcoming accessions of the legumes will be assessed cooperatively with other researchers.

3. Evaluation of test site seeding performance

Tests established in Fall 1976 at the intensive site and the mountain browse site will be evaluated for germination and vigor in May or June 1977, and for survival and growth in Fall 1977. We must also rate performance during the second growing season (1978). New tests will be seeded in Fall 1977 which incorporate more progenies from the breeding nursery (which were not available last fall) and will provide better representation of the several species under detailed study. In consultation with other project personnel, one or two additional test plot sites will be chosen in ecological zones different from the 20 hectare intensive study site. The 1977 seeding sites will be representative of the oil shale region and encompass the widest possible range of germplasm variation of the various plant materials being studied.

4. Continuation of breeding procedures for recombination

Choice of elite parent plants based on phenotype, visible appearance in the nurseries, ecotype, and seed-setting ability will be started in Spring 1977 and continue into 1978. Choices have to be based also on test-site performance in 1977 and Spring 1978. Although the latter date will be too late for transplanting parent plants into a recombination block, it is possible to control pollination in 1978 by cutting off flowering culms of undesired plants

in the various breeding nurseries. The definitive establishment of replicated clonal pieces of elite parents into crossing blocks should then follow in Fall 1978, with intercrossed seed to be harvested in 1979. Some greenhouse crossing will be tried.

We expect to place 10 to 50 parent plants in the recombination block for each new synthetic variety of each species. This may mean, as an example, two synthetics of western wheatgrass bred for improved seed-set and seedling vigor but adapted to two different ecological zones of the Piceance Basin. In addition, we propose to set up at least one special-purpose synthetic from seedlings tolerant to high salinity, which might serve several ecological zones. It is impractical to expect to release more than five new types of a given species, because of the relatively small demand for commercial seed increase of each one.

5. Seed production methodology

Controlled seed harvest will be conducted at the Fruita and Meeker nurseries in Summer 1977, by both the combine-harvester and hand harvest method. These harvest will provide the basis for determining best methods for breeding and selection of plants that will meet the important criteria of high seed yield and harvestability. A seed source that cannot be provided commercially will not likely become a part of large-scale rehabilitation specifications.

BUDGET
SUBPROJECT D(A)

	Year 2
1. SALARIES AND WAGES	
aa. Scientific Discipline Personnel	
*Co-Investigator, R. L. Cuany 100% of time for 2 months	$ 3,700
*Junior Research Associate 100% of time for 12 months	11,880
Graduate Research Assistant 50% of time for 12 months	4,400
Graduate Research Assistant 50% of time for 12 months	4,400
bb. Support Personnel	
Hourly Labor	3,000
cc. Fringe Benefits	
10.64% of *	1,658
Total salaries, wages, and annuities	29,038
2. INDIRECT COSTS	
64% of salaries, wages, and annuities	18,584
3. SUPPLIES AND MATERIALS	
Greenhouse supplies	400
Seed harvest packets and boxes	200
Field stakes, etc.	200
Chemicals for greenhouse and field	100
Pollinating Bags	100
4. PUBLICATIONS AND REPORTS	100
5. TRAVEL	
To and from research site	4,000
Scientific meetings	500
6. OTHER DIRECT COSTS	
Tractor rental	1,000
Computer	200

7.	TOTAL DIRECT COSTS	$ 35,838
8.	TOTAL SUBPROJECT COSTS	54,422

SUBPROJECT D(B)

TITLE: ECOLOGICAL-GENETIC VARIATION IN IMPORTANT NATIVE SHRUB SPECIES AND ITS INTEGRATION WITH LANDSCAPE-VEGETATION PATTERNS

PERSONNEL: Dr. Richard T. Ward, Professor
Dr. Ralph L. Dix, Professor
William Slauson, Research Associate

OBJECTIVES

There are two major objectives in this study:

1. analysis of ecotypic variation in selected shrub species
2. quantitative phytosociological description of the vegetation of the Piceance Basin.

Both are design to be pertinent to understanding reclamation and to be of use in reclamation plans. The latter will also provide the vegetation framework for ecotype and selection studies. What follows here is a summary of the current status of our investigations and a presentation of the proposed next stages of study.

CONTINUATION PROPOSAL

Ecotype Study

The general strategy for discovering if variation among populations of possible ecological significance has a genetic base or is due to plasticity of expression of a common genotype is to grow, in a common environment, materials collected from different populations. Further, it is advisable to use vegetative materials from the natural environments rather than seeds for propagation in the common garden, since the vegetative material is certain to be representative of a genotype that is adapted to that environment, while all possible recombinants represented by seed may not be so. Future studies to compare the variation within seed populations with variation in surviving plants are anticipated.

Initially a single common garden for propagation and comparison of different source materials is planned and will be located within the Intensive Study Site in the Piceance Basin. Additional plantings of the studied shrubs will be made at the Meeker Plant Materials Center to be used for replacing damaged or inviable plants in the main garden. Other gardens and selected back transplants may be established in the future, however, this is not a pressing need since our experience in other ecotype studies indicates that similar response trends are displayed in multiple gardens.

Due to the length of time required to establish a garden of shrub species and anticipating a lengthy period of measurement taking before even any preliminary results concerning shrub ecotypes can be made, it was decided in the early stage of this study to establish a variety of shrub species. Detailed measurements and analyses then can be made at any time after establishment and adequate maturation. Some measurements of phenology and growth, however, will be made as soon as possible on two or three species as described below. The species selected for study represent a variety of habitats, and varying tolerance widths. All are important constituents in one or more shrub communities of the region. They are:

Amelanchier alnifolia	Cercocarpus montanus
Artemisia tridentata	Symphoricarpos oreophilus
Atriplex canescens	Purshia tridentata
Ceratoides (Eurotia) lanata	

Population representatives will be collected for two geographic scales: 1) the broad region of western Colorado and contiguous areas in other states; and 2) within a local landscape unit of the Piceance Basin. The last will be closely related to the phytosociological gradient study of the landscape from which the different sample populations come.

For each species at least five locations from the wide geographic range will be used. For each of these collection sites, eight different individuals will be represented. Replications for one of the species will be used to test for garden homogeneity. Investigation of ecotypes along a local environmental gradient in the Piceance Basin will initially involve one or two species, which will be collected from 12-15 sites on a gradient determined in our phytosociological studies.

Correlations of different ecotypes with differences in their native environments is essential to understanding ecotypic variation. This is especially so if the correlations can be interpreted in terms of their biological (adaptive) advantages. For each population collection site environmental data on such factors as elevation, latitude, growing season length, slope direction, slope steepness, and soil characteristics will be obtained.

The following is our anticipated time table for the establishment of the shrub garden:

Spring/Summer 1977	collection of propagation material, rooting in mist
Mid-Summer 1977	rooted cuttings planted in pots and maintained in greenhouse and growth chambers
Fall 1977/ Early Spring 1978	potted plants established in main shrub garden; backup materials planted at Meeker
Summer 1978 and Continuing	measurements of phenology and growth

Depending on growth and survival, initial measurements can be taken during the summer of 1978. The first reliable and intensive measurements will be made in the following growing season. If the attempts to propagate Symphoricarpos oreophilus from dormant cuttings during winter 1977 are successful, some transplant establishment for the geographic study as early as the summer of

1977 is possible and measurements in the late summer of 1977 or spring of 1978 can be expected.

The specific measurements made on the garden material will depend in part on what will be learned in the meantime about each species' seasonal cycle and growth habits, and the measurements to be made will vary with the species. Measurements to indicate ecotypic differences in phenology, morphology, vigor and growth will be made and will include:

a. time of growth initiation
b. time of leaf expansion
c. cessation of stem growth
d. leaf fall
e. dormancy
f. leaf size
g. annual stem length growth
h. growth form

For plants which reach reproductive age, measurements will include:

a. time of flower bud expansion
b. anthesis
c. time of fruit ripening
d. seed and fruit production

Phytosociological Studies

The phytosociological studies are concerned with giving a quantitative description of the vegetation of the Piceance Basin with the potential to inform reclamation efforts and provide a context for interpreting any ecologic-genetic variation found in the projects' other plant materials investigations. The problem posed by the physiognomically diverse vegetation of the Piceance Basin to a sampling program which will allow intercommunity comparisons is formidable. Our approach to this involves essentially three different sampling procedures for each stand. The herbaceous layer is measured by area quadrats for frequency. The trees (including saplings and seedlings of tree species) are measured in larger area quadrats for density, basal area, and frequency. Shrubs, the predominant life form of the region, are measured for cover in three different strata.

Environmental measurements and estimates to be made in each stand will be limited to those which can be taken in any stand on any day. No permanent, long term equipment will be installed. The values to be recorded are: slope, exposure, elevation, slope position, parent material, soil depth, soil texture, soil structure (blocky vs. granular), soil color (dark, medium, light) and lime layer (depth). These basic measurements and estimates can be combined into various scalars for further analysis.

Our tests show that for a practiced two-man sampling team, a day may be required to adequately sample the most difficult types (tall shrublands), while up to four stands of low shrubland types may be sampled in a day.

This sampling regime will be implemented in the growing season of 1977. Data will be compiled and analysis begun in fall 1977. Standard methods of direct and indirect gradient analysis will be used to get preliminary models of the vegetation. This is the first task of articulating quantitatively the relations of the vegetation to the landscape and also to the ecotype and selection studies. The model may also reveal "gaps" in our data and thus help direct data collection for the next field season. In addition, maintenance of and addition to the project herbarium will be continued.

BUDGET
SUBPROJECT D(B)

	Year 2
1. SALARIES AND WAGES	
aa. Scientific Discipline Personnel	
*Co-Investigator, R. T. Ward 100% of time for 1½ months	$ 4,700
*Associate Investigator, R. L. Dix 100% of time for 1½ months	4,200
*Junior Research Associate 50% of time for 9 months; 100% of time for 3 months	7,425
Graduate Research Assistant 50% of time for 12 months	4,400
bb. Support Personnel	
*Secretary	850
Hourly Labor	5,000
cc. Fringe Benefits	
10.64% of *	1,827
Total salaries, wages and annuities	28,402
2. INDIRECT COSTS	
64% of salaries, wages and annuities	18,177
3. EQUIPMENT	
In excess of $1,000:	
Pop-up camping trailers (2)	3,000
Other equipment:	
Rototiller	350
4. SUPPLIES AND MATERIALS	
Plant collecting, drying and filing	500
Peat pots, perlite, growth chamber potting trays	500
Miscellaneous field and laboratory	1,000

5.	TRAVEL	
	To and from research sites	$ 4,000
	Scientific meetings	600
6.	PUBLICATIONS AND REPORTS	300
7.	TOTAL DIRECT COSTS	38,652
8.	TOTAL SUBPROJECT COSTS	56,829

SUBPROJECT E

TITLE: INTERACTION AMONG PLANT SPECIES, SOIL MATERIAL, CULTURAL PRACTICES, AND ENVIRONMENTAL PARAMETERS ON PLANT COMMUNITY ESTABLISHMENT AND RATE AND DIRECTION OF SECONDARY SUCCESSION.

PERSONNEL: Dr. C. Terwilliger, Jr., Professor
Mr. David A. Koehler, Research Associate
Mr. Douglas E. Johnson, Graduate Research Assistant

OBJECTIVES:

1) To determine the proper reseeding practices for potentially usable plant species and mixtures of plant species and their relationship to cultural practices and inputs.

2) To determine the rate and direction of plant community succession as influenced by: a) mixtures of species used in revegetation,
b) cultural practices, and
c) soil conditions

3) To develop information and guidelines for increasing the successful germination of important native plants.

CONTINUATION PROPOSAL

Revegetation Technique Plot

Beginning June 1, 1977, the revegetation technique plots will be sampled by non-consumptive quantitative methods to establish the emergence baseline of the various species seeded. Thereafter, the plots will be re-sampled at monthly intervals throughout the growing season to determine attrition and survival. Five 1/10 m "Daubenmire" quadrats will be situated in each of the sub-subplots by means of random coordinates (Payne, 1974; Daubenmire, 1959). Data recorded on each quadrat will include:

- number of plants of each species
- an estimation of cover by each species
- maximum height of each species

Subsequent reduction of this data will also yield:

- vigor (as evidenced by height indices)
- frequency
- density

Statistical analysis of field data will test the null hypothesis that fertilizer treatments, irrigation applications, and seeding techniques do not affect the emergence or survival of the species mixtures being tested. The hypothesis will be tested by subjecting the data to multivariate analyses of variance. Significant differences between and among treatments may then be detected by the application of F-tests and Tukey's "honestly significant difference" procedure (Sokal and Rohlf, 1969).

Successional Plots

Randomly placed, 1/4 m^2 plots (25 cm x 100 cm) will be located within the sub-subplots using random coordinates on a grid system. Seedling emergence data collected beginning June 1, 1977, will include plant number per unit area and mean maximum plant height. The sampling period beginning August 15, 1977, will concentrate on parameters concerned with seedling establishment; viable seedlings per unit area, mean maximum plant height, and estimated biomass per plant species. Species data will include those which are seeded as well as invader plants. Seedling height will be used as an index to plant vigor, and seedling number and biomass to compare treatments among and between groups. Significance will be tested statistically by analysis of variance procedures and Tukey's Multiple Range Test. Subsequent years data will include density, height and biomass measures.

Annual Disturbance Plot

These plots will be sampled by the same methods as the successional plots, in fact, will provide the control plots for future comparisons.

In the fall, another replicate of these plots will be constructed. The primary emphasis for these plots will be to establish moderately disturbed areas that have been altered in specific ways for definite periods. These plots will then be investigated for microbiological and secondary plant successional changes. Documentation of natural secondary succession should provide an interesting contrast to the artificially induced successional plots.

Revegetation of retorted shale

At the intensive study site two test plots will be constructed where studies can be carried out concerning plant and small animal succession and microbiological successional changes in plant communities overlying processed shale. Other studies to be enacted in the future could also utilize these plots.

The first of the successional plots will be constructed with the use of Paraho processed shale. Paraho processed shale was selected because it will be readily available and because it may be one of the major by-products of the oil shale retorting process. The second successional plot will be developed with the use of a mixture of Tosco II and Paraho processed shales. The Tosco II process may also be an important retorting method during commercial development. It has been stated in Rio Blanco Oil Shale Project's Detailed Development Plan for Oil Shale Tract C-a that their processing operation will involve both the Tosco II and Paraho methods.

Spent Shale Successional Plot (Paraho Retort Process)

Successional plots on processed shale will be used to evaluate the effect of retorted shale properties, depth, and disposition on the rate and direction of plant community succession. Species mixtures, cultural practices, and soil amendments will be tested for their ability to aid restoration of functional ecosystems on disposal sites for spent shale.

The experimental design for the successional plot will consist of three treatment variables applied in a split-split plot design (Figure E1). This basic design will be replicated three times. The sub-suplot size will be 9 x 18 meters. Main plots will consist of treatments that will simulate processed shale disposal piles presently proposed by industry and will also provide a realistic environment to approach important research questions (see Supplemental Request, February 7, 1977).

The various treatments will include:

1) processed shale without any surface covering
2) 30.5 cm soil over spent shale
3) 61 cm soil over spent shale
4) 91.5 cm soil over spent shale
5) 61 cm soil over 30.5 cm capillary barrier over spent shale
6) soil check with no spent shale

On all plots containing retorted shale, the shale will have a depth of two feet or more. The total retorted shale requirement is estimated to be 18,710 cu. meters.

Subplots on the successional plots will consist of three vegetation mixtures:

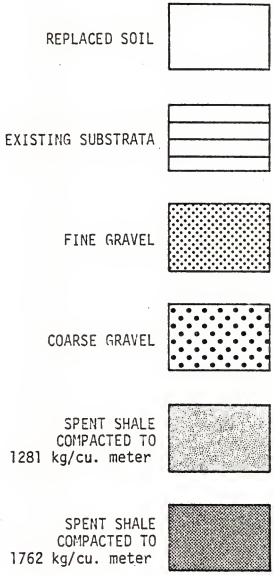
1) a native grass-forb mixture
2) an introduced grass forb mixture
3) a grass-forb-shrub mixture containing both native and introduced species

Sub-subplots will consist of three fertilizer treatments:

1) 0 kg/ha, 0 kg/ha
2) 56 kg/ha, 28kg/ha
3) 112 kg/ha, 56 kg/ha

The third fertilizer treatment will be the same as one treatment to be used on the Nitrogen-Phosphorus Balance Plots to provide an interconnecting link between

LEGEND


REPLACED SOIL
EXISTING SUBSTRATA
FINE GRAVEL
COARSE GRAVEL
SPENT SHALE
COMPACTED TO
1281 kg/cu. meter
SPENT SHALE
COMPACTED TO
1762 kg/cu. meter

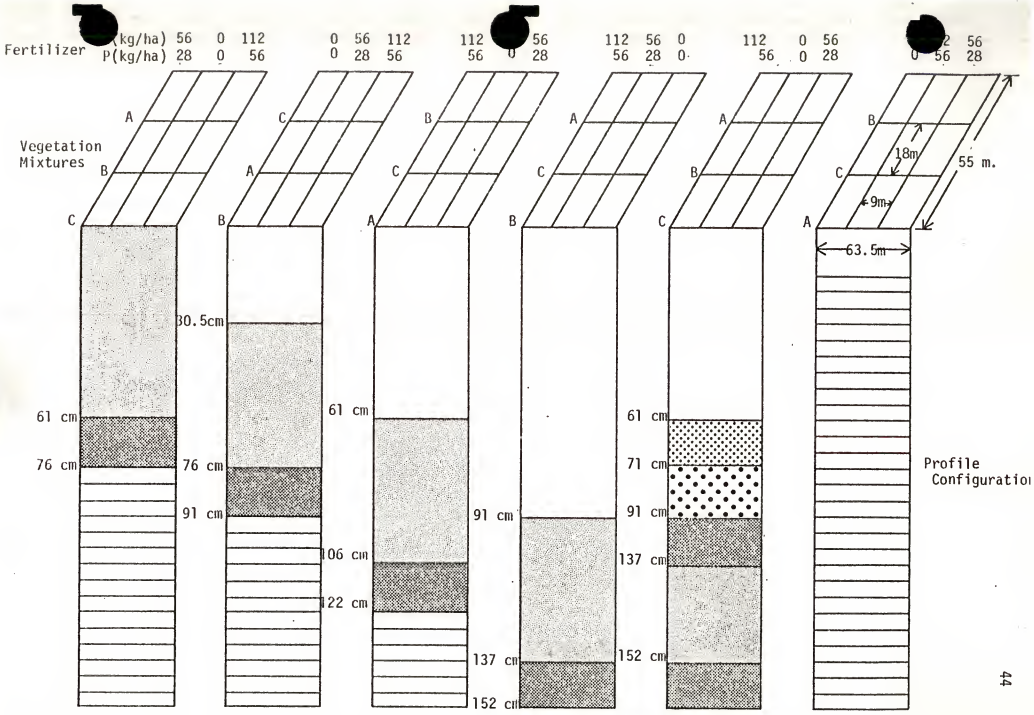


Figure E1. Processed Shale Successional Plot Using Paraho Retorted Shale (See Supplemental Request, Feb. 7, 1977)

the two plots. Nitrogen will be applied annually for five years while phosphorus will consist of only a single application the first year.

The retorted shale for the plot and the other plots requiring Paraho spent shale will be transported from the Anvil Points facility near Rifle to the Intensive Study Site, approximately 98 kilometers. Transport will be the most expensive aspect of plot construction.

Spent Shale Successional Plot (Tosco II and Paraho Spent Shale)

This test plot was not proposed in the Supplemental Proposal of March, 1976. However, because of the availability of Tosco II spent shale and because of the probability that more than one retorting process will be used, we are proposing an additional test plot to study long-term plant community succession on a mixture of two spent shales.

The profile configuration (Figure E2) for this test plot will be identical to the previously described succession plot. The main differences will be that the processed shale will consist of 65 percent Tosco II and 35 percent Paraho as is proposed in the disposal plan for the Rio Blanco Oil Shale Project's Tract C-a (Figure E2). The limited amount of Tosco II processed shale that is available dictates that the test plot will be minimal in size and only encompass approximately 0.12 hectares. Subplots will measure 6.7 x 9.8 meters. The total spent shale requirement is estimated to be 818 cu. meters. Of this, 531 cu. meters will be transported from the Colony operation in Parachute Creek. The remainder will be transported from Anvil Points. Correspondence with Colony personnel indicates their willingness to provide the Tosco II processed shale for this research effort.

Suplots on this succession plot will consist of one vegetation mixture and one fertilizer treatment that will link this plot to both the Nitrogen-Phosphorus Balance Plot and the original processed shale succession plot.

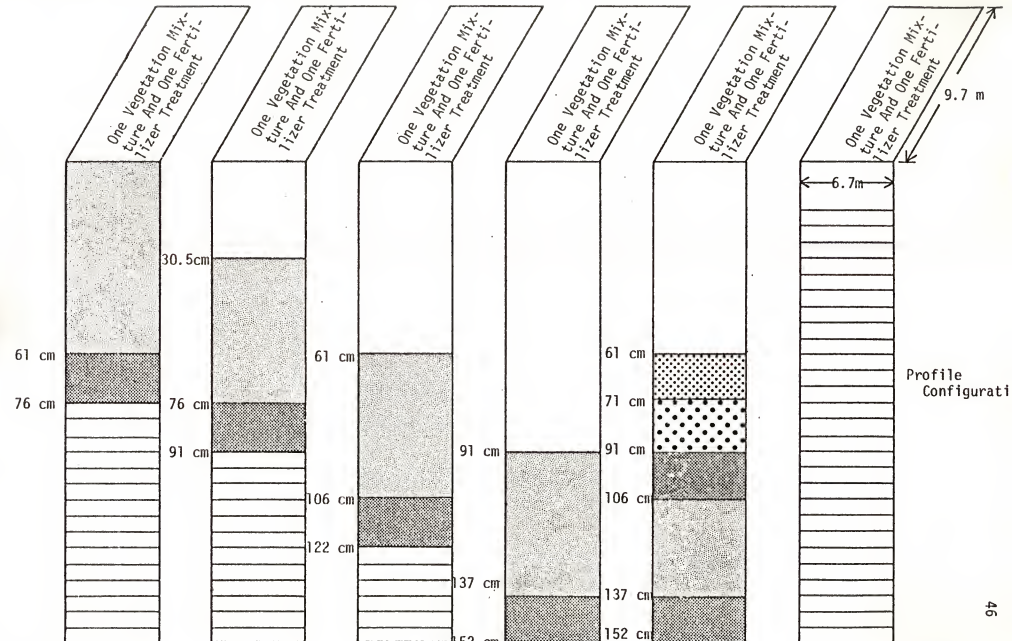


Figure E2. Processed Shale Successional Plot Using TOSCO II and Paraho Retorted Shale (See Supplemental Request, Feb. 7, 1977)

Germination and Establishment of Important Native Plants

The nature of most western reclamation sites is characterized by extreme environmental conditions (absence of a vegetative cover, limited moisture, inadequate organic matter, a harsh climate, and infertile soils). The expense of manipulating this planting environment (topsoiling, cultivation, irrigation, fertilization, intensive management, etc.) to agricultural standards is prohibitively expensive in terms of the potential agricultural value of the land. In order to avoid costly long-term inputs of management and natural resources, a viable alternative is to establish vigorous, self-sustaining ecosystems similar to native ecosystems. To accomplish this objective with any degree of predictability, however, certain gaps in current reclamation technology must be bridged.

The problems addressed here are concerned with gaps in information regarding germination qualities of several native plants. With increasing concern for extreme environments, such as are encountered during the reclamation of disturbed land, the importance of studying responses at both the upper and lower limits of a plant's tolerance becomes apparent. Such studies allow some prediction of a plant's potential adaptability in both competitive and non-competitive situations (Rorison, I. H. 1969).

Specific gaps in information emphasized by this research include: 1) lack of information on how germination requirements of native plants respond to the environmental characteristics of severely disturbed lands; 2) the need for more ecologically sensitive planting methodologies; and 3) the need for adequate guidelines for tailoring germination of important native plants to the planting environment. The purpose of the research outlined here is to develop specific information on germination requirements of several important native plants as well as the development of a methodology for determining more ecologically sensitive planting procedures. The research has been divided into several phases in order to outline a necessary sequence of events.

These phases are: 1) an intensive literature search, 2) selection of several important test plants, 3) determination of requirements for breaking dormancy, 4) determination of requirements for germination, and 5) a greenhouse demonstration of the range and optimum conditions for germination success in relation to important field conditions of daylength or aspect, soil moisture, soil texture, soil color and soil depth.

Phase I. Literature Search

The objective of Phase I is to conduct an intensive literature search on the techniques, methodologies and equipment for germination of native plants in the western United States. It has been divided into three sub-goals:

1. An annotated bibliography would be developed from an intensive library and government agency search as well as consultation with experts in the field.
2. A subject guide to the literature would be developed to provide accessibility to the bibliography.
3. A state of the art publication on the history of germination and establishment of native Western plants would be prepared.

Phase II. Selection of Test Species

Until recently, few non-economic plants have received attention concerning their cultivation. Some range plants, such as important forage grasses or those used in landscaping or horticulture (i.e., Western wheatgrass, Ponderosa pine, Colorado columbine) have been worked on extensively. Plants which are ecologically important to the shrub-dominated plant communities found in northwestern Colorado have received little attention until recently with the increased interest in drought adapted plants (i.e., Four-wing saltbush, Big sagebrush, Black greasewood, etc.). The majority of native plants which show a wide ecological amplitude, exhibit aggressive growth habits and are adapted to northwestern Colorado still have largely unknown cultivation requirements.

The plants that will be selected for this study will be based on the literature search in Phase I, two to three plants from the grass, forb and shrub categories will be selected as test plants. Criteria used in selection of these plants will be their importance for use in reclamation, availability of planting materials, adequacy of existing information, and results of present seedings at the Intensive Study Site.

Phase III. Dormancy Requirements

Seeds of most plants are unable to germinate while they are enclosed within the fruit attached to the parent plant, or for a period of time after fruit ripening and seed dispersal. Seeds whose germination is prevented by their own internal mechanisms are said to be dormant. If the seed is capable of immediate germination when subjected to proper environmental conditions, the seed is said to be quiescent or nondormant. The distinction between dormant and quiescent seed is that, in the first, germination control is due to mechanisms internal to the seed, and in the second, to environmental factors external to the seeds. Three conditions must be fulfilled before germination will begin: a) the seed must be viable, b) internal conditions of the seed must be favorable for germination, and c) the seed must be subjected to the appropriate environmental conditions.

Tests to be performed during this phase of the research are adapted from Hartmann and Kester (1975) and include:

1. Viability Test - Percentage of live seed will be determined from the tetrazolium test. Tetrazolium tests would be conducted by the Colorado Seed Laboratory on the campus of Colorado State University.
2. A series of germination tests with pregermination treatments will be conducted to determine the specific type of seed dormancy of each test plant.

Phase IV. Laboratory Germination Requirements

Both Phases IV and V can begin once pre-germination treatments are known. Both phases deal with the ranges and optimum germination conditions of the test plants involved. Phase IV is concerned with the measurement of each factor regulating germination in the laboratory. Phase V is concerned with the response of germination requirements to simulated field conditions in the greenhouse.

Using standardized seed germinators and techniques, adapted from Hartman and Kester (1975), and the Association of Official Seed Analysts (1970), a series of tests will be conducted to determine temperature, moisture and light requirements for optimum germination.

a. Temperature Requirements

Temperature is probably the single most important environmental factor that regulates germination. Different plants not only have upper and lower temperature limits for germination, but may also respond to specific seasonal or diurnal fluctuations. The overall temperature requirements tend to reflect the environment of the plant's native habitat.

Three temperatures (minimum, optimum, and maximum) will be determined for each species. This will be determined at both a constant temperature and at fluctuating diurnal temperatures of a 10^0 C difference. Each species will be germinated at the following temperatures:

1. Constant -- in degrees Centigrade: 10, 15, 20, 25, 30
2. Fluctuating -- 12 hours minimum and 12 hours maximum in degrees Centigrade: 10-20, 15-25, 20-30, 25-35.

b. Light Requirement

Light sensitivity is now recognized as a major ecological factor in adaptation of plant species. Light-sensitive seeds are often small and germination is favored by placement near the soil surface where the seedlings can emerge

quickly and begin photosynthesis. Seedling survival is reduced or eliminated by planting at too great a depth or in close proximity to other plants where there would be an intense competition for light.

By contrast, plants with light-inhibited seeds tend to be found in dry desert environments where seedling survival would be enhanced if the seeds germinated at somewhat greater soil depths where there is less heat and more moisture.

The light requirement of many seeds tends to disappear with dry storage and can often be overcome by chilling, alternating temperatures, or chemical treatments. In the proposed research, all species will be germinated in each temperature test in both the light and dark. The light period will be of 12 hours duration each 24 hour period in both the constant and fluctuating temperatures. Moisture conditions will be maintained at an optimum level during all of the light and temperature tests.

c. Moisture Requirements

The rate of water absorption for germinating seeds has three phases: a) an initial rapid uptake due to imbibition, b) a slow intermediate period, and c) a second increase in uptake as the radical emerges and the seedling develops. Because of their colloidal nature, dry seeds have great absorptive power which varies as a function of the nature of the seed, the permeability of the seed covering, the availability of water, and the temperature. Higher temperatures increase water uptake.

The moisture supplied to the germinating seed may affect both the germination percentage and the germination rate. Germination percentage tends to be equal over most of the range of available moisture from field capacity to permanent wilting percentage. Differences among species become evident as the moisture content of the soil approaches dryness (Hartmann and Kester, 1975).

Adequate moisture will be provided in all germination tests until the temperature and light requirements are determined. At this time, the lower limit of moisture will be determined to achieve germination at optimum temperature and lighting conditions. Each species will be tested for the lowest level of moisture it will germinate at with five different moisture levels.

d. Germination Time

All germination tests will be recorded every 5 days to determine the germination percentage at each 5-day interval up to 30 days.

Phase V. Greenhouse Simulation of Field Conditions to Develop Guidelines for Field Plantings

In order to develop guidelines for field planting of native plants, it is necessary to know how the germination requirements of particular plants respond to the basic planting environment variables of soil texture, color, moisture, temperature, planting depth, and day length. All of these factors interact with each other and modify the overall planting environment to either enhance or suppress seed germination. For example, it has been found that where soil conditions are not ideal, the germination resistance (dormancy requirements) of the resulting seed crop is high; and vice versa, better growing conditions lead to lower germination resistance (Gordon, 1973).

In most reclamation planting, it is neither economically or ecologically desirable to try to develop a controlled germination environment over large areas to ensure germination success. By taking advantage of microhabitats created by topographic variations (slopes, slope facings, landforms) and soil types, planting techniques can be tailored to the germination requirements of the plant and its planting environment.

The major factors influencing seed germination are temperature, moisture, and light. Temperature is modified by soil color, day length, soil moisture, and planting depth. Soil moisture is modified by soil temperature, soil

texture, planting depth and precipitation. Lighting is modified by day length, soil texture, soil color, aspect, and planting depth. Because few of these variables can be kept constant in the field and each influences each other, guidelines which are developed from combination of factors showing the range of germination response to simulated field conditions will have greater applicability to actual field conditions.

In this phase of the research, potted samples in a greenhouse with temperature and lighting controls will be utilized to develop the planting guidelines. Factors to be measured and correlated are:

1. Soil Color - 3 treatments (light, medium, dark). A thin layer of colored sand would be spread over each pot to standardize the soil colors.
2. Soil Texture - 5 treatments (sandy, sandy loam, loam, clay loam, and clay).
3. Soil Moisture - 3 treatments (dry, moist, wet). The soil in the pots would be brought to field capacity once at the beginning for dry; again ten days after the first for moist; and again at 20 days and at 30 days for wet. Percent soil moisture will be measured per treatment at 15, 25, and 35 days.
4. Planting Depth - 5 treatments (0.5 cm, 1.0 cm, 2.0 cm, 4.0 cm, 6.0 cm.)
5. Day Length - 3 treatments (14 hours, 12 hours, 10 hours). Lighting will be controlled for minimal levels with supplemental artificial lights, photocell switch and timer.

A planting guideline chart will be developed for each species from the results of the experiment. The following is used for illustration. For each combination of soil texture and soil color, the optimum germination results will be listed giving: moisture regime, planting depth, percent germination, and germination time.

PLANTING GUIDELINES SPECIES X

SOIL TEXTURE	SOIL COLOR		
	Light	Medium	Dark
Clay	Long Day Moisture Planting Depth Germination % Germination Time Medium Day Moisture Planting Depth Germination % Germination Time Short Day Moisture Planting Depth Germination % Germination Time		
Clay Loam			
Loam			

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BUDGET
SUBPROJECT E

		Year 2
1.	SALARIES AND WAGES	
	aa. Scientific Discipline Personnel	
	*Co-investigator, Charles Terwilliger, Jr. 100% of time for 1½ months	$ 3,675
	*Junior Research Associate, David Koehler, 100% of time for 12 months @ $990/month	11,880
	*Junior Research Associate 100% of time for 12 months @ $990/month	11,880
	2 Graduate Research Assistants 50% of time for 12 months	8,800
	bb. Support Personnel	
	Hourly Labor	3,000
	cc. Fringe Benefits	
	Public Employees Retirement Association, 10.64% of *	2,919
	Total salaries, wages and annuities	42,154
2.	INDIRECT COSTS	
	64% of salaries, wages, and annuities	26,979
3.	EQUIPMENT	
	Soil test equipment	1,000
	Meterological equipment	1,500
4.	SUPPLIES AND MATERIALS	
	Plant markers and stakes	500
	Earth moving tools	300
	Tool boxes	250
	Storage cabinets (field)	500
	Miscellaneous	1,000
5.	PUBLICATIONS AND REPORTS	1,500
6.	TRAVEL	
	To and from research site	2,500
	Scientific Meetings	500

7.	OTHER DIRECT COSTS	
	Laboratory soils analyses	$ 1,500
	Laboratory seed analyses	400
	Computer services	500
8.	TOTAL DIRECT COSTS	54,104
9.	TOTAL PROJECT COSTS	81,083

SUBPROJECT F

TITLE: THE IMPORTANCE OF MYCORRHIZAL FUNGI IN SALVAGING AND STABILIZING SPENT OIL SHALE WITH NATIVE VEGETATION.

PERSONNEL: Dr. F. Brent Reeves, Jr., Associate Professor
Mr. Tom Moorman, Graduate Research Assistant
Miss Jean Kiel, Graduate Research Assistant

OBJECTIVES

The objectives of this subproject are to determine 1) the absolute numbers of mycorrhizal spores in disturbed versus undisturbed soil, 2) the various types of mycorrhizal fungi present in undisturbed sites, and 3) the population dynamics of mycorrhizal fungi.

CONTINUATION PROPOSAL

Because all the samples of the important plants of the native ecosystem in the oil shale region are mycorrhizal, we are reasonably convinced that the lack of mycorrhizal spores is very important in determining the success of rehabilitation. Our goal now is to determine the absolute numbers of mycorrhizal spores in the disturbed vs. undisturbed soils, i.e., numbers of spores per gram of soil, and most importantly, the viability of the spores. Currently we are developing accurate methods for sieving the spores from the disturbed and undisturbed soil and checking their germination. Numbers of spores mean nothing if they are not capable of establishing mycorrhizal relationships with the native vegetation. The results of this aspect of the study hopefully will strengthen our hypothesis.

Another very important aspect of this work is determining the various types (species) of mycorrhizal fungi present in undisturbed sites or native vegetation. If more than one species of mycorrhizal fungi is present in an undisturbed site, it is essential that when that site is disturbed the disturbed site is seeded with higher plants which will maintain the fungi so that rapid recovery of the ecosystem can be achieved. This goal can be

attained by the continued survey of the native vegetation for the occurrence of mycorrhizae and the species of mycorrhizal fungi present in both the roots and the soil (some mycorrhizal fungi do not produce spores).

From the soil collected at the dump site, we are extracting mycorrhizal spores and establishing pot cultures so that artificial inoculation on native plants for future study can be made. Our goal is to establish pot cultures of the major species of mycorrhizal fungi so we can make better comparative studies as to the relative effectiveness of each species of mycorrhizal fungi on each selected species of native host. The data for determining the major species of fungi will be generated from the sieving experiments. From these pot cultures we intend to grow the native hosts (with and without mycorrhizae) under various conditions including a medium of disturbed soil over processed shale.

We believe that an extremely important aspect of this work is a study of the population dynamics of the mycorrhizal fungi. If data indicate that the number of viable spores is quite variable with the seasons, then this information may indicate when the best time for soil disturbance and/or storage occurs--that is, disturbance would best occur during a period of maximum number of viable spores so that the potential for the reestablishment of mycorrhizae is increased. How the details of this aspect of the research will proceed will depend on the rate and accuracy of the information gained in the preceeding work.

Our preliminary results with the bioassay of the soil were so good that this experiment is currently being repeated using total raw soil (100% soil, disturbed and undisturbed) as well as the diluted soil as in the initial experiment. If the bioassay remains successful, then this may prove to be an extremely useful method of quickly and cheaply estimating the mycorrhizal rehabilitation potential of a given disturbed soil.

Finally, we must correlate our work with the information generated at the Intensive Study Site. We have collected soil (both ripped and mixed) at this site to analyze for numbers of mycorrhizal spores. This information will be correlated with that provided by Dr. Klein in his studies of other microorganisms. We are particularly interested in checking the relative success of reseeded vegetation on the test plots and their degree of mycorrhizal infection. It is our intent to monitor these seedlings as they develop. Also we intend to survey the invasive vegetation which volunteers on the annual disturbance plots for mycorrhizal development. This information can provide us baseline data for potentially predicting the role and innoculum potential of mycorrhizal spores under field conditions.

The current strategy for reclamation includes possible introductions of native or exotic legumes able to fix nitrogen. Several recent investigations have demonstrated that certain but not all legumes grow better and have increased nodulation when they are mycorrhizal. Since the legumes represent a potential natural mechanism to reduce nitrogen fertilizer requirements we must examine those suggested for use for their response to mycorrhizal infections. Dr. Cuany currently has several legumes under cultivation as potential elements in the revegetation efforts. We will cooperate with Dr. Cuany in using his materials for these studies.

Our ultimate aim is to determine the relative importance of mycorrhizae in successful rehabilitation techniques in our semi-arid environment. Because this area of research has never been investigated, our ideas must remain somewhat flexible as data is gathered and analyzed. If, as we suspect, the numbers of mycorrhizal fungi are significantly reduced with disturbance then we must devise methods of increasing the numbers of those essential species of fungi if we expect a natural ecosystem to become established and be maintained. Currently we have a total void in the technology for producing large numbers of mycorrhizal fungi. Hopefully successful directions towards

applied technology can be gained through our collaborative efforts in defining the real problems associated with rehabilitation in semi-arid environments.

BUDGET
SUBPROJECT F

	Year 2
1. SALARIES AND WAGES	
aa. Scientific Discipline Personnel	
*Co-Investigator, F. B. Reeves 100% of time for 1½ months	$ 3,360
Graduate research assistants, Tom Moorman and Jean Kiel, 50% of time for 12 months	8,800
bb. Support Personnel	
Hourly Labor	3,000
cc. Fringe Benefits	
Public Employees Retirement Association, 10.64% of *	358
Total Salaries, Wages and Annuities	15,518
2. INDIRECT COSTS	
64% of Salaries, Wages, and Annuities	9,932
3. SUPPLIES AND MATERIALS	
Greenhouse supplies	500
Reagents and chemicals	400
Glassware, slides, coverglasses	400
Microbiological media	400
Photosupplies	300
Reference materials, Xerox, etc.	300
4. EQUIPMENT	
In excess of $1,000: Growth Chamber, Sherer 3610	3,500
Other equipment:	
Colony counter	500
Copy camera back	400
Repair and replacement	400
5. PUBLICATION AND REPORTS	400
6. TRAVEL	
Colorado--Intensive site and subsistence	2,500
Scientific Meetings	1,000

7.	CONSULTANT SERVICES	
	Dr. Martha Christensen, Univ. of Wyoming	$ 3,000
8.	TOTAL DIRECT COSTS	29,518
9.	TOTAL PROJECT COSTS	39,450

BUDGET JUSTIFICATIONS

1. Salaries and Wages

Both Moorman and Kiel are currently working on this project full time for their degrees. They now have experience with mycorrhizae and their work is progressing.

Wagner, an undergraduate, began work last June, 1976, and has been a major contributor to the project. His knowledge of the higher plants has been invaluable to the mycorrhizae studies.

5. Equipment

Growth chamber. To establish and maintain pot cultures of selected mycorrhizal fungi we need a plant growth area which is free from potential contamination. An isolated greenhouse would be preferable but this is not possible. The alternative is a plant growth chamber.

Other equipment. A copy camera back for our copy apparatus to provide slides for scientific presentations and other materials for reports and publications is requested. The colony counter will be used in estimating numbers of saprobic fungi as correlated with viable mycorrhizal propagules.

8. Consultant Services

Consistent with ERDA's suggestion on the initial proposal, the mycorrhizal and field expertise of Dr. Martha Christensen will be employed again.

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REHABILITATION POTENTIAL AND PRACTICES OF COLORADO OIL SHALE LANDS

Progress Report for Period
June 1, 1976 - May 31, 1977

Phillip L. Sims
Principal Investigator

Colorado State University
Fort Collins, Colorado 80523

February 1977

Prepared for

THE U.S. ENERGY RESEARCH AND DEVELOPMENT ADMINISTRATION
UNDER CONTRACT NO. E(11-1)-4018

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ABSTRACT

Substantial progress has been made towards implementing all of the prescribed studies and satisfying the stated objectives since the Oil Shale Rehabilitation Project was actively initiated in June 1976. Concurrent with implementation, research objectives were substantively defined and supplemented without distracting or departing from the original purpose. Current studies are designed to fill voids in the present status of knowledge regarding lands disturbed by an impending oil shale industry in Colorado. The efforts of all contributing investigators have therefore been integrated and directed toward the goal of developing methodologies requisite for restoring diverse and complex ecosystems which will require only a minimal amount of maintenance or input of scarce resources.

An intensive study site southeast of Oil Shale Tract C-a has been obtained through a Cooperative Agreement with the Bureau of Land Management. Following this agreement, most subprojects were initiated at the intensive site. Additional programs will be implemented as spent shale becomes available this summer. Studies conducted principally in the laboratory and greenhouse, such as the microbiological and plant genetic studies, have achieved significant results. Other studies that require more intensive field application will not generate data until next field season.

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INTRODUCTION

Research conducted by each investigator during the 1976 funding period resulted in significant contributions to the overall goal of the project. This report describes these accomplishments along with significant results that have been obtained. The following paragraphs give a brief summarization of the progress to date for each subproject.

A. Resource Management Unit Handbook

Existing information has been integrated into descriptive characterizations of ecosystems occurring in the Piceance Basin. Sources of this information included vegetative community maps (Cook, 1974), Soil Conservation Service (SCS) soil resource inventories, and vegetation-soil studies, plus available climatic, geological, geomorphological, and hydrological information. Ecosystem characterizations thus derived have been incorporated into a Handbook which also describes the risk factors associated with land disturbances. The Handbook contains a dichotomous key to the resource management units, designed to facilitate unit identification by laymen or workers unversed in the regional ecology. The first draft of the manuscript has been completed at this date. Publication of the Handbook will be completed by June 1, 1977.

B. Long-Term Fertility Requirements

Field studies have not been initiated for this subproject due to the unavailability of processed shale from the Paraho project. However, in anticipation of retorted shale availability this summer, preparatory

investigations have been completed. The activities this year involved the study of pertinent literature and developing a plan and strategy for the plot work that will be set up as soon as the retorted shale is available. Arrangements for purchasing and transporting the wood materials, sewage sludge, and chemical fertilizer have been pursued so that the plots can be established early in the summer of 1977. Equipment for N and P analyses is being ordered and/or prepared and procedures have been investigated so that time will not be lost when this study gets underway.

C. Role of Soil Microorganisms

Major efforts were directed the first year towards the development of techniques to be used to sample the intensive study site. A total of 224 soil samples were taken during summer and fall 1976 from six revegetation plots in the general region. Microorganism populations were enumerated for each sample, nitrification activity and non-symbiotic nitrogen fixation rates were measured, and methods for determination of fungal versus bacterial contributions to carbon flow processes were evaluated. In January 1977, 62 soil samples were taken from the intensive study site to provide a baseline inventory of microbial populations. These are in the process of being analyzed at the present time. Studies in progress will evaluate rehabilitation techniques for their ability to provide maximum microbial nutrient cycling and energy flow.

D(a). Development of Improved Strains of Grasses, Legumes, and Forbs through Selective Breeding

Plant materials selection and improvement has advanced during 1976 through seed collection, planting of breeding nurseries, and two types of

field trials. Emphasis has been centered on the grass species previously proposed (western wheatgrass and Indian ricegrass) and likewise on legume species (lupine, Utah sweetvetch, and cicer milkvetch). Many germplasm sources have been collected, and those with sufficient seed have been planted as spaced plants in breeding nurseries, as seeded rows in two field trials in the Piceance Basin, and in seed production trials in western Colorado. Seed harvested from older nurseries has been prepared for controlled-stress germination tests. The first evaluations of field-site performance from 1976 plantings will begin in spring 1977. These evaluations are to explore genetic differences which will lead to ecotype selection and breeding of desirable characteristics into improved strains for rehabilitation uses.

D(b). Suitability of Native Shrubs and Forbs for Shrubland Restoration

The presence and extent of ecotypic differentiation of selected shrub species and the nature of vegetational variation on the landscape are being studied in relation to implications for reclamation. Adaptation by local populations to environmental gradients is indicated by natural variation in genetically determined ecological traits and natural variation in phytosociological structure. An understory of the evolutionarily derived correlations of genetic variation with environmental and phytosociological variation will aid in matching genetic material to the environmental situtations under reclamation. The presence, extent, and nature of the genetic variation is being investigated by propagating plant materials from different sources in common gardens. The ecological significance of any variation found will be examined by relating the ecotypic variation to gradients of vegetation structure and the physical

environment. During the first field season, various phytosociological and genecological methods were developed to measure these various variations and gradients.

E. Interaction among Plant Species, Soil Material, Cultural Practices, and Environmental Parameters on Plant Community Establishment, Rate and Direction of Secondary Succession

Three plots were constructed, reseeded, and treated in the fall of 1976 to accomodate the proposed revegetation research. The Successional Test Plot contains 108 9x18 m subplots, with buffer zones between. Treatments applied were two mulch treatments, three fertilizer application levels, and six species mixtures. Each combination was replicated three times. The Revegetation Technique Plot contains six subplots, each measuring 17x92.5 m. Each subplot encloses 24 sub-subplots measuring 6x8 m and separated by buffer zones. Three of the subplots will be irrigated, three will not. Other levels of treatment are: fertilized vs. non-fertilized, three species mixtures, and four seeding techniques using various methods, depths, and rates. The Annual Disturbance Plot consists of 6x8 m subplots subjected to four intensities of disturbance. Each treatment was replicated twice.

F. Importance of Mycorrhizal Fungi

The hypothesis tested was that delays in reclamation procedures designed to create natural ecosystems on disturbed, semi-arid lands are due, in part, to a lack of essential mycorrhizal fungi in the soil. The initial research involved a comparison of a severely disturbed area adjacent to an undisturbed ecosystem similar to the proposed processed shale dump site. Results of this comparison revealed that 100% of the invasive plants (all the plants on the disturbed site) were non-mycorrhizal

whereas in the natural undisturbed ecosystem 86% of the plants were mycorrhizal.

Using corn as an indicator plant for mycorrhizal infection, a bioassay of the disturbed vs. undisturbed soil for potential mycorrhizal infection revealed that 60-90 days were required for mycorrhizal formation in disturbed soil but only 30 days were required for the undisturbed soil. Preliminary studies using saprobic fungi as indicators show that the number of fungal propagules are considerably reduced in disturbed soil. Further research designed to corroborate these data is planned and preparation for laboratory and field trials of mycorrhizal vs. non-mycorrhizal plants is being made.

The overall project objective is to develop detailed guidelines for reclamation of disturbed lands in the oil shale region. Specifically, we are seeking ways to initiate reestablishment of complex and diverse plant communities with minimum use of scarce resources. Currently, field research has been initiated on non-retorted shale plots that will investigate the relationships between types of vegetation and soil disturbances and microbial processes. During the coming year research results should provide insight into the relationship of re-invasion of plant species and soil microbial population dynamics and activity. Similarly, as plants emerge on the revegetation techniques study area some interesting soil treatment:plant materials:microbial relationship interactions should be apparent. Hopefully, the interrelationships between the subprojects will make important contributions to improved guidelines for rehabilitation of disturbed oil shale lands. In the coming years the interrelationships will be investigated on soil/retorted shale plots to elucidate guidelines useful for processed shale disposal areas.

INTENSIVE STUDY SITE

SITE SELECTION

In June, 1976, the principal investigator and co-investigators met with BLM officials from the Meeker Area Office and, in the course of a field reconnaissance, selected four possible locations for the intensive study site. The alternative sites were all situated between Ryan School and 84 Ranch, south of Tract C-a. Each had soils deep enough to accomodate the proposed retorted shale plots, according to a Soil Conservation Service soil survey completed in 1975. The following four locations were considered.

1. N½, SW¼ of S 4, T2S, R98W--north of Cascade Pipeline.
2. SW¼, SW¼ of S 33, T1S, R98W and E½, SE¼ of S 32, T1S, R98W--west side of road, half-way from jeep trail to 84 Ranch HQ.
3. NE¼, NW¼ of S 33, T1S, R98W and SW¼, NE¼.
4. NE¼, SW¼ of S 33, T1S, R98W and SW¼, NE¼--east of road and north of Division of Wildlife exclosure.

Final site selection occurred in early July. Basic criteria which were considered included: soil depth, access, size and shape of each area, aesthetics, and distance to water and electricity. Site #1 was chosen as the most suitable location. It is accessible from two sides--the main C-a Tract headquarters road on the east and the "Pipeline Road" on the south. The area is large enough to easily accomodate a 20 hectare study area in a variety of configurations. A power line extends up

Stake Springs Gulch, 2.4 kilometers north. Water is also available in Stake Springs Gulch, at 84 Ranch.

Physically, the site forms a semicircular basin, with a generally northern or northeastern exposure. The topography is slightly to moderately undulating. Erosion, though severe in spots, is not as pervasive as on the alternative sites. Soils are clay loams, loamy sands, or sandy clay loams and are generally deep as evidenced in the gullies which traverse the site. These are up to 1 or 2 meters deep and exhibit a suitable growth medium to that depth. The vegetation is the most profuse and diverse of any of the alternative sites. Sagebrush is relatively tall and dense; the interstices between shrubs have good ground cover with desirable grasses dominating the understory. Young pinyon-juniper, though widely scattered, has invaded the area.

A survey of the topographic configuration and boundary of the study area was made by project personnel (Appendix I, Figure 1). The area was located by reference to the brass cap marker at the corner of S 4, 5/8, R98W, T2S. As the boundary was circumscribed, direction of sight and backsight, distance, topographic arc, and elevational differences were recorded. Elevation differences were also measured and recorded on four transects, interior to the tract, at 4-chain intervals.

A formal survey was conducted in late October, 1976, by a registered professional land surveyor. The 20 hectares which was selected, surveyed and fenced is a parcel of land lying in the W½ of Section 4, T2S, R98W of the 6th P.M., County of Rio Blanco, State of Colorado. The approximate location of the site is shown in Appendix I, Figure 1.

BASELINE INVENTORY OF THE SITE

Vegetation

Two basic plant communities occupy the intensive study site. In July and August, 1976, these were sampled extensively to provide baseline information and quantitative data. A total of less than 60 species was encountered on the site, owing in part to the lateness of the sampling season. Many spring forbs had already disappeared from the composition of the local communities. Also, a dry spring affected composition by inhibiting the germination and growth of forb species which would ordinarily have occurred in local populations. A list of species encountered on the intensive study site is shown in Appendix I, Table 1.

Line intercept transects and m^2 quadrats were sampled in each of the site's principal plant communities--sagebrush and pinyon-juniper. These studies were implemented to obtain measurements of tree and shrub canopy intercept, relative cover by all indigenous plant species and frequency of occurrence by those species. Ten 30 m transects were sampled in each of the two major communities. Five m^2 quadrats were sampled along each transect.

"Daubenmire plots" (1/10 m quadrats) were utilized to estimate biomass of shrub, forb, and grass species encountered. Every fifth plot was clipped and weighed by species to provide an ongoing calibration of estimates. Clipped samples of "green herbage" were also obtained for later drying to provide "wet" to "dry" weight conversion ratios. A total of 200 quadrats was sampled in the more expansive sagebrush community, while only 100 quadrats were sampled in the pinyon-juniper community.

(A). In the Pinyon-Juniper Community, the most abundant grasses were slender wheatgrass (*Agropyron trachycaulum*), Indian ricegrass (*Oryzopsis hymenoides*), needleandthread (*Stipa comata*), and prairie junegrass (*Koeleria cristata*), occurring in 52%, 48%, 44%, and 24% of the subplots, respectively (Appendix I, Table 2). Ground cover contributed by each of these species was as follows: slender wheatgrass--1.89%, Indian ricegrass--0.39%, needleandthread--1.51%, and prairie junegrass--0.26% (Appendix I, Table 3). Biomass estimates for these species were as follows: slender wheatgrass--30.3 kg/ha (oven-dry weight), Indian ricegrass--12.1 kg/ha, needleandthread--51.8 kg/ha, and prairie junegrass--11.9 kg/ha (Appendix I, Table 4).

The most frequently occurring forb species in this community were miner's candle (*Cryptantha sericea*)--64% frequency, Hood's phlox (*Phlox hoodii*)--44%, bullhead gilia (*Ipomopsis congesta*)--40%, lobeleaf groundsel (*Senecio multilobatus*)--38%, and Nuttall goldenweed (*Haplopappus nuttallii*)--22% (Appendix I, Table 2). Miner's candle contributed 0.65% ground cover, Hood's phlox 0.82% ground cover, and longleaf phlox(*Phlox longiloba*) 0.17% ground cover (Appendix II, Table 3). Of the forbs yielding the largest biomass, miner's candle averaged 24.0 kg/ha, stemless goldenweed (*Haplopappus acaulis*) 16.5 kg/ha, and Nuttall goldenweed 10.6 kg/ha (Appendix I, Table 4).

Big sagebrush (*Artemisia tridentata*) with 44% frequency, and broom snakeweed (*Gutierrezia (Xanthocephalum) sarothrae*), with 26% frequency, were the most abundant shrubs (Appendix I, Table 2). Big sagebrush also exhibited 10.02% ground cover (Appendix I, Table 3). Big sagebrush was also the most productive species in this community, yielding 111.8 kg/ha

of oven-dried biomass; prickly pear (*Opuntia polycantha*) produced 32.1 kg/ha (Appendix I, Table 4).

(B). In the Sagebrush community, needleandthread with 50% frequency; Indian ricegrass, 47%; Sandberg bluegrass (*Poa secunda*), 35%; western wheatgrass (*Agropyron smithii*), 32%; slender wheatgrass, 31%; and bottlebrush squirreltail (*Sitanion hystrix*), 29% are the most abundant grasses (Appendix I, Table 2). Those grass species providing the greatest ground cover include needleandthread, 1.65%; slender wheatgrass, 1.06%; Indian ricegrass, 0.50%; western wheatgrass, 0.36%; and bottlebrush squirreltail, 0.32% (Appendix I, Table 3). Western wheatgrass was the most productive grass, yielding 65.7 kg/ha, followed by needleandthread and Indian ricegrass, yielding 42.9 kg/ha and 25.0 kg/ha, respectively (Appendix I, Table 5).

Hood's phlox, 56%; miner's candle, 34%; and bullhead gilia, 21%, were the most frequently occurring forbs (Appendix I, Table 2). Hood's phlox had a ground cover of 1.30% and miner's candle had 0.35% ground cover (Appendix I, Table 3). Hood's phlox also produced more biomass than any other forb--34.0 kg/ha. Scarlet globemallow (*Sphaeralcea coccinea*) produced 5.2 kg/ha (Appendix I, Table 5).

Big sagebrush was present in 67% of the subplots. Broom snakeweed was present in 18% (Appendix I, Table 2). Ground cover on the quadrats by big sagebrush averaged 15.77% (Appendix I, Table 3). This species also produced more biomass than all other species combined--277.1 kg/ha. Prickly pear produced 54.8 kg/ha (Appendix I, Table 4).

(C). In a study of transect intercept by shrub and tree canopy, the sagebrush community indicated an intercept, or cover, of 24.0%. Of this total, 23.3% was by big sagebrush (Appendix I, Table 6).

In the Pinyon-Juniper Community, cover by juniper (*Juniperus osteosperma*) equalled 19.7%, big sagebrush 13.3%, and pinyon (*Pinus edulis*) 6.6% (Appendix I, Table 6).

Soil Depth

A grid design was implemented for soil depth samples. A soil auger was used to facilitate the sampling. Soil depth samples were taken from each corner of the 48.5 hectare project area on which the intensive study site was to be located. Other samples were taken at 4-chain intervals in a north-south direction, at 8-chain intervals in an east-west direction. This design permitted the collection of a total of 50 soil depth samples.

Soil Testing and Analyses

Composite soil samples were taken from each of the six revegetation technique subplots. Four cores were drilled from the surface to consolidated material at approximately equidistant intervals down the middle of each subplot. The cores were placed in a bag and thoroughly mixed. Samples were then analyzed by the CSU Soil Testing Laboratory. Results are shown in Appendix I, Table 7.

CONTRACTUAL ARRANGEMENTS

BLM officials in the state, district, and area offices were kept apprised of the location, intent, and progress of the study. Efforts were extended to maintain contact with all involved agency personnel as preliminary studies and preparation progressed. In early September, pursuant to a BLM request, a Memorandum of Understanding was prepared and submitted for their approval. The Memo would authorize a cooperative agreement between CSU and BLM for use of the intensive study site.

Subsequently, the BLM requested that a Draft Environmental Analysis Report be prepared. This was prepared and submitted, and approval of the Memorandum of Understanding was extended in October.

Job descriptions were written for heavy equipment to construct the revegetation technique, successional, and annual disturbance plots and a short access road, to hydromulch experimental plots, and for fence construction around the site. These were submitted to CSU's Purchasing Department, along with a list of potential contractors. Bid Request Forms were mailed to interested bidders and firm bids were received during the second week of October.

Several seed dealers were contacted for their prices for the approximately 40 species to be seeded in the test plots. Sources for all species were located and seed was ordered by October 1 and received by November 15, 1976. During the actual seeding, it became apparent that a specialized seed drill would be necessary to accomplish the task within the restricted design and small area of the subplots. A tractor and drill were leased from a rancher near Meeker for that purpose.

A tour of the site was conducted in early December with area BLM officials. A general concurrence was expressed by the group that the conditions of the Memorandum of Understanding had been complied with and that obligatory conditions had been fulfilled.

SUBPROJECT A

TITLE: INTERPRETATION AND CHARACTERIZATION OF IMPORTANT NATURAL ECOSYSTEMS IN THE PICEANCE BASIN

PERSONNEL

Dr. Charles Terwilliger, Jr., Professor
Mr. James A. Tiedeman, Graduate Research Assistant

TIME EXPENDED BY CO-INVESTIGATOR FOR CURRENT TERM

Dr. Terwilliger--100% time for 1 month

OBJECTIVE

To prepare a guide to the ecosystems of the Piceance Basin describing the risk factors associated with disturbance of each ecosystem.

PROGRESS TO DATE

The first draft of the manuscript has been completed. Work on a revised Ecosystems Map of the Piceance Basin to accompany the manuscript is in progress. Review and publication of the Handbook will be completed by June 1, 1977.

The draft manuscript includes 200 pages plus 30 pages in the appendix. An annotated outline is given below.

I. Introduction

A general discussion of the approach and a justification of the work along with objectives and scope are included.

II. General Description of the Piceance Basin

This discussion includes location, general climate, geological material, soil, vegetation and land ownership.

III. Key to the Ecosystems and Resource Management Units in the Piceance Basin

A dichotomous key using vegetation, soil and land form characteristics was developed to guide a user of the handbook to an identification of a specific landscape.

IV. Guide to the Use of the Handbook for Characterization and Interpretation

This chapter includes a discussion and definition of terms, concepts, and abbreviations used in the chapter on interpretation.

V. Characterization and Interpretation of the Resource Management Units

Eighteen resource management units are discussed in detail in terms of the following major topics:

A. Description
B. Reclamation Considerations
   1. Hazards and Risks
   2. Revegetation Requirements and Alternatives
C. Vegetation Analysis
D. Soil Profile Description
E. Laboratory Chemical and Physical Analysis
F. Soil Interpretive Properties
G. Soil Use Limitations

As an example, the discussion and interpretations of one resource management unit is attached at the end of this report.

DESCRIPTION OF THE APPENDICES IN THE INTERPRETIVE CHARACTERIZATION HANDBOOK

A. Scientific and common names of plants in the Piceance Basin.

B. List of species expected to be most successful for revegetation within each resource management unit.

C. Monthly precipitation data for 1975 and 1976 at 11 locations in the Piceance Basin.

D. Average annual precipitation, minimum and maximum annual precipitation for the 95% confidence limits, and 80% chance annual precipitation based on precipitation records for the 1951-1970 period (Wymore, 1974).

E. Estimated irrigation water required (acre-ft.) for spring planted and full season irrigation of 10 acre revegetation areas on a horizontal surface (Wymore et al., 1974).

F. Resource management units listed in order of most favorable to least favorable for vegetation.

G. Resource management units listed in order of decreasing understory herbage productivity under natural conditions.

H. Literature review

Ecosystems
Vegetation
Domestic livestock and wildlife
Geomorphology
Geologic materials
Soils
Climate
Hydrology
Plant Succession

I. Methods used in the study.

RESOURCE MANAGEMENT UNIT

The following is a sample of the contents from Chapter 5 of the Interpretive Characterization Handbook and covers the Grassland Ecosystem.

GRASSLAND ECOSYSTEM

RMU-17--Bald ridges/shallow, gravelly loams

I. Description

This unit, characterized by high elevation dry ridge tops, occurs at the highest elevations in the Piceance Basin on north to east running ridges. Because of its ridgetop position and aspect toward the prevailing wind direction, a venticular wind effect occurs where the winds increase in velocity as they pass over these exposed ridges. Winds blow very strongly throughout the year with almost all the snow being blown off in winter. This prevents adequate soil moisture recharge so that these sites are excessively dry. Summer winds also have a desiccative

effect upon plants intensifying the drought conditions. Plants are also subjected to extremely low temperatures due to the lack of snow cover. The soil is not adequately protected by plant cover with over 30% bare ground exposed to wind erosion resulting in the development of a gravel pavement on the soil surface. The grassland ecosystem is the only type in the basin that occupies the windswept ridgetops at high elevations.

The unit has a vegetative cover of low shrubs, forbs, and grasses. The most common shrubs are fringed sagebrush (*Artemisia frigida*) and Douglas rabbitbrush. Dominant grasses are Indian ricegrass, needleandthread, and wheatgrass species. The characteristic forbs are mat penstemon (*Penstemon caespetosus*), spearleaf wildbuckwheat, and nuttall goldenweed.

Soils are less than 20 inches deep with more than 25% coarse fragments. The geological material is primarily shale of silt to fine sand sized particles. Elevations range from 7,500 to 8,500 feet with slopes from 0 to 30%. The mean annual precipitation is estimated to be 16 to 20 inches. Mean annual air temperature is less than 40°F; mean summer air temperature is 58 to 65°F.

This unit is used primarily for grazing cattle and sheep. If undisturbed, this unit would reach a stable plant community dominated by needleandthread. Most of this unit has been and still is heavily grazed by cattle and sheep.

II. Reclamation Considerations

A. Hazards and Risks

This unit is very fragile and disturbance would cause severe wind and water erosion of the shallow soils. The wind blows what little

soil that develops off the ridge where it accumulates on the leeward slopes allowing the establishment of taller sagebrush and serviceberry shrubs. Areas near the Cathedral Bluffs receive the most intensive wind erosion.

Any physical soil disturbance on this unit would bring the very gravelly subsoil to the surface producing a poor growth medium for plants. Drought, high winds, shallow and gravelly soil, exposure to temperature extremes, low soil loss tolerances, and a remote location make revegetation extremely difficult and any disturbance extremely hazardous.

Development of tailing ponds, mine dumps, roads and excavations have severe limitations due primarily to shallow depth to rock. These areas are small and any disturbance would affect the surrounding areas. Dumping of mine spoils on the leeward slopes and in the valley heads adjacent to the ridgetops would be less likely to erode than if dumping occurred further downstream in the watershed; however, diversions are needed to divert water flow around these areas.

B. Revegetation Requirements and Alternatives

Fertility levels for phosphorus are medium, indicating that only low phosphorus-requiring plants can be planted without application of phosphorus fertilizer. Potassium levels are high so that most species used for revegetation do not require potassium fertilizer. Application of nitrogen may not be necessary and if applied, weed invasion could become a problem.

Fertilizer should be applied prior to planting or at the time of planting to allow placement at the proper depth. Fertilizer applied to

the surface would be lost by wind and water erosion. Thirty pounds of phosphorus fertilizer (P_2O_5) per acre is recommended. When nitrogen fertilizer is utilized application should follow emergence of seeded plants.

Application of mulches would be desirable and often necessary to establish a satisfactory stand of seeded plants. Mulches conserve soil moisture and help minimize erosion. Straw mulches worked into the soil but not buried would be the most desirable. Planting, if in rows, should be perpendicular to the prevailing easterly wind in a rounded or corrugated furrow pattern. This furrowed surface effect would cause blowing soil material to settle in the depressions. Planting on the leeward side of these furrows would be most successful where neither excessive erosion or accumulation would be a problem. The "micro east" aspect thus provided would also provide a more optimal moisture environment for seedling establishment. Steep slopes greater than 20% should be planted on the contour and mulched for wind protection. More gentle slopes would be preferred, however.

Snow fences could be constructed on these ridges, perpendicular to wind direction to hold the winter snow and thus increase soil moisture recharge. This would increase moisture available to plants for revegetation and reduce the effect of blowing soil damaging seedlings. Planted areas need to be fenced for protection from livestock for at least one and perhaps as much as three growing seasons.

The following tables, numbered as they occur in the Handbook, provide descriptive vegetation (Table 66) and soils data (Tables 67, 68, and 69) for the Grassland Ecosystem Unit.

III. Vegetation

Table 66. Total standing crop green weight biomass, percent composition and percent constancy for RMU-17.

Total estimated range in standing crop green weight biomass is 600-1800 lbs./acre, with a mean of 1150 lbs./acre.[1]

Number of Stands: 4

Species	% Composition	% Constancy[3]
Shrubs and Trees		
Artemisia frigida	4.5	100
Ceratoides lanata	1.9	25
Chrysothamnus viscidiflorus	3.6	75
Phlox multiflora	2.7	50
Phlox longifolia	+[2]	25
Grasses and Grasslikes		
Koeleria cristata	14	75
Stipa comata	10.6	75
Agropyron smithii	8.9	75
Oryzopsis hymenoides	3.3	100
Poa secunda	3	50
Forbs		
Haplopappus nuttallii	10.3	75
Penstemon caespetosus	9	100
Hymenoxys acaulis	11.8	50
Eriogonum tristicum	4.7	75
Linum lewisii	1.6	25
Astragalus tequitarius	2.2	25
Crepis acuminata	1.2	25
Cryptantha sericea	+	75
Astragalus diversifolius	+	50
Eriogonum spp.	+	25
Penstemon stricta	+	25
Cirsium spp.	+	25
Trifolium gymnocarpon	+	25
Chaenactis douglasii	+	25
Taraxacum officinale	+	25
Artemisia ludoviciana	+	25
Comandra umbellata	+	25

Table 66.--Continued

Species	% Composition	% Constancy
Hedysarum boreale	+	25
Astragalus boreale	+	25
Number of other species = 1	+	
Total % Composition of species with less than 1% composition each marked with "+" =	5.0	

[1]Based upon 1975 which received nearly average to slightly below average precipitation.

[2]"+" indicates less than 1% composition.

[3]% Constancy is the percent of stands sampled that the particular species was found to be present.

Table 67. Laboratory data and relative ratings for RMU-17.[1]

Horizon		A1	C						
Depth in Inches		0-3½	3½-11						
pH (Paste)		7.2 neutral	7.6 mildly alkaline						
E.C. mmhos/cm (salinity class)		0.7 none	0.4 none						
Saline/Alkaline		non	non						
SAR		good 0.19	good 0.64						
ESP		---	---						
% Lime		high 2.0	high 9.4						
% Base Saturation		79	100						
% Organic Matter		high 6.0	high 4.2						
% Organic Carbon		3.53	2.47						
% Total N		0.460	0.325						
C/N		good 8.02	good 7.6						
P ppm		high 14.8	low 4.8						
K ppm[2]		high 222.3	low 58.5						
NH_4OA Extractable Cations meq/100 g	K	0.57	0.15						
	Na	0.14	0.41						
	Mg	2.64	2.88						
	Ca	24.58	32.93						
H_2O Soluble Ions meq/l	SO_4	0.77	0.84						
	Na	0.38	1.10						
	Mg	1.24	.90						
	Ca	6.73	4.98						
CEC		35.34	35.24						
% Sand		57	61						
% Silt		38	37						
% Clay		5	2						

[1] Definition of terms in the soil section of "How to Use the Handbook" part (b).

[2] Calculated from meq/100 g.

Table 68. Soil properties for RMU-17.[1]

Depth in Inches	USDA Texture	Unified	AASHO	% by Wt. Coarse Fragments >3"	% by Wt. Coarse Fragments >2 mm
0-3½	very gravelly sandy loam	SM, SC	A-1	5	50
3½-11	very gravelly sandy laom	SM, SC	A-1	50	80

Depth in Inches	% Material Less Than 3" Passing These Sieves				Liquid Limit	Plasticity Index	Permeability In/Hr	Available Water Capacity	
	(5.0 mm)	(2.0 mm)	(0.4 mm)	(.08 mm)				In/In	Total Soil
0-3½	55-75	40-50	25-35	10-20	15-25	0-5	0.6-6.0	.04-.09	1-1.5
3½-11	50-70	45-55	30-40	10-20	15-25	0-5	0.6-6.0	.05-.07	

Depth in Inches	Shrink Swell	Corrosivity		Erosion Factor		Wind Erod.	Shear Strength	Compressibility
		Steel	Concrete	K	T			
0-3½	very low	moderate	moderate	.27	1	T./ac./yr.	med	low-med
3½-11	very low	moderate	moderate	.27		117-180	med	low-med

Depth in Inches	Perm. of Compacted Soil (seepage)	Susceptibility to Piping	Compaction Characteristics	Depth and Hardness of Bedrock	Potential Frost Action	Flooding
0-3½	med-low	med	good	10"	low	none
3½-11	med-low	med	good	rippable		

[1]For explanation of properties see soil section of "How to Use the Handbook" part (c).

Table 69. Soil limitations for RMU-17.[1]

Use		Rating	Problems, each alone sufficient for the classified rating
Septic Tank Absorption Fields		Severe	Depth to rock, slopes over 15%
Sewage Lagoons and Tailing Ponds		Severe	Depth to rock, slopes over 7%, coarse fragments
Landfill	Trench	Severe	Depth to rock, slopes over 15%
	Area	Severe	Hard to reclaim, slopes over 15%
Cover for Landfill		Poor	Thin layer, area reclaim, slopes over 15%
Shallow Excavations		Severe	Depth to rock, slopes over 15%
Buildings without Basement (Dwelling Size)		Severe	Depth to rock, slopes over 15%
Buildings with Basements		Severe	Depth to rock, slopes over 15%
Small Commercial Buildings		Severe	Depth to rock, slopes over 7%
Local Roads and Streets		Severe	Depth to rock
Trafficability		Good	
Source Material	Roadfill	Poor	Areas hard to reclaim, slopes greater than 15%, excess fines
	Sand and Gravel	Poor	Areas hard to reclaim, excess fines
	Topsoil	Poor	Thin layer, small stones, area reclaim
Ponds and Reservoirs			Depth to rock, steep slopes
Embankments, Dikes & Levees			Thin layer
Excavated Ponds Aquifer Fed			No water
Drainage			Not needed
Irrigation			Soil blowing, complex slopes, depth to rock, shallow rooting depth, too fast water intake, droughty
Terraces and Diversions			Not needed
Establishment of Grassed Areas			Droughty, shallow rooting depth, steep slopes

Table 69.--Continued

Use		Rating	Problems, each alone sufficient for the classified rating
Recreation	Camp	Severe	High winds, soil blowing, slopes over 15%
	Picnic	Severe	Soil blowing, high winds, slopes over 25%
	Playground	Severe	Depth to rock, slopes over 6%
	Trails	Slight Moderate Severe	Slopes less than 15% (Most of the unit is less than 15% slope making trail locations desirable especially due to viewpoint potential.) Slopes 15-25% Slopes 15+%

[1]For explanation of limitations see soil section of "How to Use the Handbook" part (d).

WILDLIFE HABITAT SUITABILITY

Habitat Elements:

Grain and Seed	Grass and Legume	Wild Herb	Hardwood Trees	Conifer Plants	Shrubs	Wetland Plants	Shallow Water
Very Poor	Poor	Poor	Very Poor	Very Poor	Poor	Very Poor	Very Poor

Potential as Habitat for:

Openland Wildlife	Woodland Wildlife	Wetland Wildlife	Rangeland Wildlife
Very Poor	Very Poor	Very Poor	Poor

SUBPROJECT B

LONG-TERM FERTILITY MAINTENANCE ON LAND DRASTICALLY DISTURBED BY OIL SHALE DEVELOPMENT

PERSONNEL

Dr. Burns R. Sabey, Professor
Dr. William A. Berg, Associate Professor

TIME EXPENDED BY CO-INVESTIGATORS FOR CURRENT TERM

Dr. Sabey--none
Dr. Berg--none

Neither investigator was alloted time during the 1976 funding period.

OBJECTIVES

Long-term fertility requirements and methods of meeting these requirements on deficient soil materials disturbed by oil shale development in northwestern Colorado will be determined.

PROGRESS TO DATE

Processed shale from the Paraho retort facility will not be available in sufficient quantities to fulfill the required research design until summer, 1977. Therefore, field studies were not activated this past season and efforts were concentrated on preparation for the coming one. An extensive review of literature relative to this subproject was conducted and completed. The design for the configuration and structure of the plot is complete and sampling methods have been determined. These are outlined in the Renewal Proposal. Equipment for determing fertility

levels (Block Digestor) is currently being assembled. The purchase and transport of fertilizers, sewage sludge, and wood chips has also been arranged.

SUBPROJECT C

THE ROLE OF SOIL MICROORGANISMS AS INDICATORS AND POSSIBLE CONTROLLING FACTORS IN PLANT SUCCESSION PROCESSES ON DISTURBED SOILS

PERSONNEL

Dr. Donald A. Klein, Associate Professor
Dr. James P. Nakas, Research Associate
Mr. Nicholas Nagle, Research Technician
Ms. Linda Smith, Research Assistant

TIME EXPENDED BY CO-INVESTIGATOR FOR CURRENT TERM

Dr. Klein--100% time for .5 months

OBJECTIVES

1. To monitor microbial activities and characteristics in revegetation plots which have been in place for four to five years at the study area, to determine characteristics of the microbial populations and their capabilities.
2. To evaluate microbial responses and changes in numbers and activity during reestablishment of plant communities on disturbed soils, using the annual disturbance, successional, revegetation technique and spent shale successional plots which are being developed at the intensive study site.
3. To develop techniques for evaluating the ability of specific plant types to stimulate nitrogen fixation in the rhizosphere.
4. In laboratory test systems, to determine the role of plant material decomposition on microbial processes. This portion of the work will

utilize plant materials derived from laboratory and field studies to determine if breakdown products from different plant types will have specific effects on nitrogen fixation and nitrification activities.

PROGRESS TO DATE

During the first year, the major effort was directed towards development of techniques which will be used during the spring of 1977 at the intensive study site. Field and laboratory studies were completed to gain information on the following parameters; on existing revegetation plots:

- Soil bacteria and actinomycetes on a sodium caseinate medium
- Fungi by use of a rose bengal medium
- Nitrifiers by a most-probable-number assays
- Nitrification activity by measurement of ammonia oxidation rates
- Evaluation of fungal versus bacterial contributions to carbon flow processes.

The major goal of this subproject is to determine which rehabilitation techniques will lead most rapidly and efficiently to soil which will be capable of providing microbial nutrient cycling and energy flow typical of mature ecosystems.

MATERIALS AND METHODS

Soil Samples

Soil samples have been taken from the following test sites:

Plot Numbers	Site	Number of Samples Taken
1	Low Sagebrush	36
2	Low Pinyon-Juniper	48
3	High Pinyon-Juniper	48
4	High Mountain Browse	36
5	High Elevation Processed Shale (Black Sulfur)	28
6	Anvil Points Processed Shale Plot	28
7	Successional Test Plots	8
8	Revegetation Technique Plots	18
9	Annual Disturbance Plots	36

The plots 1-6 were sampled during the summer and fall of 1976, and the plots 7-9 were sampled during the first part of January, 1977, to provide background information on microbial populations in the soils prior to the beginning of plant growth in spring.

At the sampling sites 1-4, marker posts were set up at the ends of each replication plot set, and 1.5-2.0 kg samples (0-10 cm depth) were taken at the center of each sub-plot, avoiding plant growth in the first preliminary sampling. The samples were stored at room temperature in self-sealing plastic bags during and after transport to the laboratory. Samples were held in larger plastic bags with added excess water to maintain the soils in a humidified environment.

Sample sets 5 and 7 were taken at the center of each of the sub-plots, again avoiding excess plant growth. For the initial samples at the intensive study area, approximately one-third of the possible plots for each of the test areas were taken. After receipt at the laboratory, all soil samples were sieved, using a 2 mm mesh sieve to remove rocks,

roots and other debris. The samples were then stored at room temperature in self-sealing bags.

Soil Microbial Enumeration Techniques

Fungi were enumerated using Rose Bengal Agar, consisting of 10 mg of dextrose, 5 gm peptone, 1.0 gm of monobasic potasium phosphate, 0.5 gm $MgSO_4 \cdot 7H_2O$, 0.33 gm of Rose Bengal, 20 gm of Agar and 1,000 ml of deionized H_2O_2. This was sterilized, and after cooling, 3 ml of streptomycin solution was added to the media, using procedures of Martin (1950). The actinomycetes and bacteria were enumerated with sodium caseinate agar, consisting of .2 gm sodium caseinate, 5 gm K_2HPO_4, .2 gm $MgSO_4 \cdot 7H_2O$, .01 gm of $FeCl_3$, 15 gm of agar and 1,000 mg of H_2O.

Eleven grams of the sifted soil was poured in a standard phosphate dilution blank and shaken for 15 minutes on a reciprocal shaker at 124 rmp, diluted, and inoculated onto spread plates using 0.1 ml aliquots. Plates were incubated at room temperature for two weeks before being counted, to assure maximum expression of colonies.

pH

Soil pH was taken by pouring 50 ml of the soil solution from the enumeration bottle and was then stirred until a stable reading was observed on the pH meter.

Organic Matter

The sifted soil was weighed out in three 0.3 gm amounts to which 3 ml of 1 N potassium dichromate was added. Six ml of conc. H_2SO_4 was quickly added, swirled for 10 seconds, and allowed to stand for 10 minutes, after that time 30 ml of H_2O was added. The solution stood

overnight to allow the sediment to settle. Five ml of the solution used to read the absorbance at 610 nm using a Bausch and Lomb spectrophotometer. Standard soils containing 1 and 2% organic matter, obtained from the Colorado State University soil testing laboratory, were used as standards.

Nitrate Activity Assay

Nitrification activity was assayed by adding 50 gm portions of the test soils to 4 petri plates, with three being replicates and the fourth being a control. To the three experimental soil samples, 10 ml of ammonium sulfate solution, .5 gm K_2HPO_4, 5 gm $(NH_4)_2S_4$, 1,000 ml H_2O were added to the soil using a syringe to cover the entire surface of the plate. The plate was covered and placed in a sealed incubator at room temperature, which was kept humid by trays of water. At two week intervals 14 gm aliquots were air dried and analyzed for nitrate using the Orion nitrate electrode model #93-07 and Orion reference electrode model #90-02, connected to a Corning pH/mv meter. The soil sample was emptied into a flask to which was added 50 ml H_2O, .5 ml AgF, .5 ml KF, .5 ml of conc. acetic acid, and 1 gm CaOH. The flask was shaken on a reciprocal shaker at 125 rpm for 30 minutes and filtered through Whatman #1 filter paper. The nitrate electrode was lowered into the filtrate and millivolts were recorded and read against a standard curve for nitrate to determine μg NO_3^-N per gm soil.

Nitrogen Fixation

Nitrogen fixation activities of soils and plants have been carried out using procedures provided by Hardy et al. (1968) and Hardy, Burns and Holsten (1973). Specific equipment used in the laboratory includes a

Varian Herograph model 1200 flame ionization gas chromatograph, and an integrator-recorder to allow calculation of peak areas. Standards of acetylene and ethylene were obtained from the Applied Science Laboratories, State College, Pennsylvania.

The separation of acetylene from ethylene was carried out by use of a 1/8x6 foot stainless steel column of Poropak Q (Water Associates, Mildord, Massachusetts) with a column bath temperature of 70°C.

Separation of Fungal vs. Bacterial Contributions to Mineralization Processes

To determine the possible changes in fungal versus bacterial contributions to mineralization processes in test soils, the basic radiotracer mineralization procedure of Harrison, Wright and Morita (1970) has been combined with the antibiotic additions suggested by Anderson and Domsch (1973), using a 20 minute incubation period.

Results to Date

Existing treatment plot analyses. To the present time, basic analyses have been completed for four of the plots. Generally, data from the revegetation plots that have been in place for 4-5 years suggest that the soils in the native (undisturbed), scraped, and plowed areas, both in favorable and unfavorable aspects (north and south facing slopes), do not show major changes in decomposer characteristics in relation to management and topographic variables.

The data for the low sagebrush plot (84 Mesa area) are given in Table C1. For the favorable aspect samples, the scraped soils sub-plots show a trend towards slightly high fungal, bacterial and actinomycete populations, although the standard error values indicate that these are

not particularly strong. A similar trend is suggested for the unfavorable aspect plots, although again this is not strong. For the organic matter and pH values, the only point of interest is the decreased organic matter levels on the native and plowed areas, and generally higher pH values on the unfavorable aspect and slope samples, being in the range of 8.3-8.5.

This same trend is shown for the samples for the low elevation pinyon-juniper plot (Table C2), where the soils from unfavorable (south aspect) slopes have higher pH values. Another point of interest is that the microbial populations for the scraped and plowed sub-plots tend to have higher microbial populations, although with the standard error values, these are not significant. No clear trends are evident for the nitrification values, which were read at six weeks of incubation.

Available data for the retorted shale revegetation technique plots at the anvil point site are summarized in Table C3. The major point of interest is the significant decrease in fungal populations in soils which had U.S. Bureau of Mines (USBM) materials added, except where the materials were covered with 24 inches of topsoil, and the significant increases in organic matter in the plots which contained higher concentrations of the retorted shale material. This is probably a reflection of the 3-6% residual carbon left in the spent shale following retorting.

The data which are available for the Black Sulfur Creek shale rehabilitation site are presented in Table C4. In comparison with controls, there appears to be a slight trend towards decreased fungal populations in USBM retorted shale materials used, and a suggestion of higher bacterial populations. On this plot the USBM materials showed a higher pH range, as indicated in Table C4. In addition there was a significant

Table C1. Microbiological characteristics of rehabilitation plot soils at 84 Mesa site (Plot #1).[a]

Aspect Treatment	Microorganisms/gram soil			Soil Organic Matter	Soil pH	Nitrification Rates
	Fungi x 10^{-4}	Bacteria x 10^{-6}	Actinomycetes x 10^{-6}			
Favorable						
Scraped	1066.0±22.0	19.8±1.4	24.7±2.3	1.57±0.14	7.8	-[b]
Native	37.4± 3.8	17.4±2.2	22.6±3.9	1.64±0.01	7.7	-
Plowed	38.7± 2.5	28.8±3.8	17.0±1.9	1.73±0.11	7.8	-
Unfavorable						
Scraped	53.8± 2.7	30.0±3.9	29.0±3.9	1.90±0.21	8.3	-
Native	50.9± 5.3	27.9±2.8	36.1±4.7	1.13±0.06	8.6	-
Plowed	45.0±15.3	36.2±3.5	43.0±7.8	0.92±0.07	8.5	-

[a]Source Book 76-13. Total sub-plots = 36, mean and standard errors given.

[b]Data analysis not complete.

Table C2. Microbiological characteristics of rehabilitation plot soils at the Low Pinyon-Juniper plot.

Aspect Treatement	Microorganisms/gram soil			Soil Organic Matter	Soil pH	Nitrification Rates
	Fungi x 10^{-4}	Bacteria x 10^{-6}	Actinomycetes x 10^{-6}			
Favorable						
Native	28.08±5.00	22.20± 3.19	28.47±2.07	3.36± .62	8.3	3.99±1.99
Scraped	39.77±8.84	28.57±11.66	46.83±5.33	3.35± .62	8.3	2.88±1.29
Plowed	90.55±4.96	34.10± 5.51	44.98±7.2	2.96± .32	8.4	4.11± .68
Unfavorable						
Native	36.98±6.55	21.77± 1.82	30.43±1.52	3.29±1.16	8.7	1.35± .251
Scraped	42.01±1.63	24.34± 3.31	26.5 ±2.33	3.68± .31	8.5	3.54±1.06
Plowed	44.8 ±8.52	24.63± 1.73	33.23±1.42	3.65± .23	8.6	3.65± .83

Source: Book 76-13. Mean and standard errors given.

Table C3. Microbiological characteristics of retorted shale rehabilitation plots at Anvil Points site (Site #7).[a]

Aspect	Treatment		Microorganisms/gram soil: Fungi x 10^{-4}	Bacteria x 10^{-6}	Actinomycetes x 10^{-6}	Soil Organic Matter	Soil pH	Nitrification Rates
Control Soils		N	22.9 ±11.5	46.5 ±10.38	62.65± 3.66	2.85±.56	7.6	-[b]
		S	40.3 ±32.3	32.5 ±13.5	41.95±10.68	3.07±.66	7.9	-
USBM Materials								
	Spent shale leached	N	4.84± .01	33.4 ± 6.92	40.77± 5.24	5.70±.60	8.0	-
		S	3.37± .275	15.75± 2.25	34.25± .75	5.33±.07	8.1	-
	Leached 6" soil cover	N	7.80± 1.00	36.25± 7.27	48.0 ±10.03	3.36±.19	8.3	-
		S	5.34± 1.71	34.50± 9.02	69.2 ±14.29	3.01±.506	8.0	-
	Not leached 24" soil cover	N	14.1 ± .50	38.25± 2.25	45.5 ± 1.50	3.18±.03	8.2	-
		S	27.8 ±16.4	17.7 ± 1.75	26.0 ± 2.00	2.75±.220	8.2	-
TOSCO Materials								
	Spent shale leached	N	67.9 ± 2.87	18.37± 9.65	106.00±63.18	7.07±.160	7.8	-
		S	26.9 ±12.5	30.5 ± .50	58.25± .250	7.11±.401	7.8	
	Leached 6" soil cover	N	13.2 ± .601	31.80± 5.21	55.80±10.28	4.59±.611	8.2	3.70±1.35
		S	11.6 ± .90	44.00± 4.01	62.25± 7.75	2.92±.280	8.4	4.19± .967
	Not leached 12" soil cover	N	17.70± 2.35	22.5 ± 3.96	45.8 ± 6.82	3.93±.21	6.9	4.79± .772
		S	13.6 ± 1.40	33.60± 5.06	52.2 ± 4.76	2.5 ±.641	7.1	-

[a]Source Book 76-13. Means and standard errors given.

[b]Data analysis not completed.

Table C4. Microbiological characteristics of retorted shale rehabilitation plots at the Black Sulfur Creek site.[a]

Aspect Treatment		Microorganisms/gram soil			Soil Organic Matter	Soil pH	Nitrification Rates
		Fungi x 10^{-4}	Bacteria x 10^{-6}	Actinomycetes x 10^{-6}			
Control Soils	N	35 ± 3.4	264±109	475±115	1.80±0.11	7.7	-[b]
	S	30 ± 0.4	224± 89	342± 82.7	1.90±0.16	7.3	-
USBM Materials							
Spent shale leached	N	32 ±23	395± 5	565±165	5.54±0.14	8.0	-
	S	26 ±10	460± 85	767± 27	5.32±0.18	8.2	-
Leached 6" soil cover	N	48 ±14	340± 95	535± 90	1.74±0.05	7.8	-
	S	6.1± 1.7	242± 33	279± 24	1.92±0.21	6.9	-
Not leached 12" soil cover	N	6.1± 1.3	350± 99	631±253	1.89±0.15	7.5	-
	S	5.6± 1.4	609±163	531±400	1.90±0.16	7.4	-
TOSCO Materials							
Spent shale leached	N	42.5± 5	271±244	422±322	7.55±0.06	7.4	-
	S	31.0± 0.5	347± 28	732± 8.2	7.53±0.01	7.4	-
Leached 6" soil cover	N	43.3±27	206± 53	347± 48	1.96±0.07	7.8	
	S	39.8± 4	233± 20	449± 43	1.91±0.08	7.7	-
Not leached 12" soil cover	N	31.3± 7	367±157	348±195	2.25±0.07	7.6	-
	S	3.2± 0.2	140± 50	283± 83	3.06±0.52	7.7	-

[a]Source Book 76-84, 28 samples analyzed. Means and standard errors given.

[b]Data analysis not completed.

increase in organic matter in the TOSCO and USBM materials, based on the assay used in this study. Again, this was most likely caused by residual carbon in the spent shale. Thus, at least with use of the USBM type materials, it would appear that there are changes in microbial populations which may persist over longer time periods in spite of the intensive management which was used on these test sites, including fertilization, leaching, and seeding.

Intensive Study Area Samples

The samples from the intensive study area, which were taken on January 7, 1977, are being analyzed at the present time, and these data will be available for the final report from the first year of studies.

Nitrogen Fixation Studies

Results available to date suggest that the techniques which have been developed will be adequate to detect nitrogen fixation in soils and plant root samples. Calculations available at the present time suggest that it will be possible to detect nitrogen fixation at rates as low as 0.01 μ moles C_2H_2 reduced$\cdot min^{-1}\cdot$mg fresh plant material^{-1}.

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SUBPROJECT D

PLANT MATERIALS--ECOLOGICAL-GENETIC VARIATION OF IMPORTANT NATIVE SPECIES, SELECTION AND PRODUCTION OF PREADAPTED PLANTS FOR RECLAMATION, AND THEIR INTEGRATION WITH LANDSCAPE-VEGETATION PATTERNS.

The presence of genetic differences between populations of native species is important for reclamation because it means that there are different adapted forms which will have varying potential for reclamation of different sites. These differences in potential are especially important if they are expressed through differences in ecological position within the vegetation or landscape.

The identification, characterization, and propagation of many populations of a species, each with unique reclamation possibilities, is a step in the direction of more controlled and predictable reclamation technology. It is also an essential first step towards the artificial breeding and selection and maintenance of plant forms with special relevance to reclamation. Understanding the different vegetation-landscape relations of each ecotype is desirable because vegetation structure, if known, is a sensitive indicator of the complex environment to which the ecotype is adapted. Further, the predisturbance vegetation of a site to be reclaimed will reflect the general nature of the environment within which the reclaimed communities will be developed.

Two separate investigations of plant materials follow. The first (DA) deals with legumes, forbs, and grasses, and the selection and production of preadapted types for reclamation. The second (DB) deals with

the identification and interpretation of ecotypic variation of shrubs and provides a phytosociological background for understanding the ecologic position of the species investigated in both sections.

SUBPROJECT D(A)

SELECTIVE BREEDING OF GRASSES, LEGUMES, AND FORBS TO DEVELOP IMPROVED STRAINS THAT CAN BE ESTABLISHED ON DISTURBED SITES IN OIL SHALE AREAS TO PRODUCE A STABILIZED ECOLOGICAL COMMUNITY.

PERSONNEL

Dr. Robin Cuany, Associate Professor
Mr. Walter Padilla, Research Assistant

TIME EXPENDED BY CO-INVESTIGATOR FOR CURRENT TERM

Dr. Cuany--100% time for 1 month

OBJECTIVES

1. Collect and assemble germplasm sources.
2. Evaluate spaced plants in two nurseries, and clonal propagules or progenies under controlled stress.
3. Evaluate seeded progenies in intensive site and satellite field plantings.
4. Use suitable breeding procedures for recombination and progeny testing to develop improved strains.
5. Coordinate research on best means of multiplying and planting the improved strains.

PROGRESS TO DATE

Germplasm Sources and Collections

The proposed list of species to be tested remains unchanged until field evaluations in progress should indicate any alteration or

reemphasis. Present studies are concentrated on the following species, listed below in the order of their priority.

Common Name	Botanical Name
Grasses:	
1. Western wheatgrass	*Agropyron smithii*
2. Indian ricegrass	*Oryzopsis hymenoides*
*3. Kentucky bluegrass	*Poa pratensis*
4. Sheep fescue	*Festuca ovina*
*5. Hard fescue	*F. ovina duriuscula*
Legumes:	
1. Lupine	*Lupinus* spp.
2. Utah sweetvetch	*Hedysarum boreale utahensis*
*3. Cicer milkvetch	*Astragalus cicer*

The western wheatgrass and Indian ricegrass have received most attention to date in the grasses as have lupines in the legumes. Other species will receive more concentrated study in future efforts.

The germplasm sources differ among each species: Table D(A)1 lists origins and approximate number of sources obtained for each species. Further source collections will be made in and outside of Colorado. A few accessions with small amounts of seed have been lost due to aged seed, dormancy problems, and disease problems of seedlings in the greenhouse. Some potential native seed sources could not be tapped, due to unfamiliarity with their locations and phenological patterns in the 1975 season, and low seed production in the 1976 season. Every native collection involves acquiring at least two live specimens and seed if available. The

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*Those marked by asterisks are introduced, not native. Bluegrass and fescues are of secondary importance.

Table D(A)1. Seed sources and number obtained from each.

Species	Source					
	WRPIS[1]	SCSPMC[2]	Named Varieties	Fellow Researchers	Colorado Collections	Commercial Lots
Western wheatgrass	4	15	5	33	43	
Indian ricegrass	12	8	1	2	31	2
Kentucky bluegrass	58		7	50	2	
Sheep fescue	14	1			4	
Hard fescue		2				
Lupine					40	
Utah sweetvetch					10	
Cicer milkvetch		1		7		

[1]Western Regional Plant Introduction Station.

[2]SCS Plant Materials Center.

live specimens are kept in a collection nursery (which can also produce seed) at the CSU Agronomy Research Center in Fort Collins, Colorado.

Most of the Colorado collections listed as sources for many of the species were made by the co-investigator and/or his graduate research assistant. Ten collection trips were made in 1975 and seven trips in 1976. Collections were conducted in the Piceance Basin and neighboring areas (e.g. Battlement Mesa, Douglas Creek, and Meeker area), and various other locations scattered over the entire state (e.g. San Luis Valley, South Park, North Park, near Colorado Springs, and Colorado City). A late frost in the spring of 1976 severely damaged lupine seed set at the lower elevations in the Piceance Basin. Seeds were therefore collected only from plants at higher elevations (above 2,236 meters).

Breeding Nurseries

From acquired germplasm, seedlings were grown in a greenhouse during winter, 1975-1976, for 1976 nursery transplanting. An Indian ricegrass nursery of 16 sources (20 plants per source) and a western wheatgrass nursery of 47 sources were established in Fort Collins in summer 1976, along with two western wheatgrass nurseries in Meeker at the SCS Upper Colorado Environmental Plant Center. One Meeker nursery consists of 56 sources of adult plants (taken from a three year old Great Plains ecotype nursery) and the other contains 25 sources of western wheatgrass seedlings as a partial replicate of the Fort Collins seedling nursery. The nursery plants are being evaluated for rhizomatous spread, survival, disease incidence, height, seed set, and seed quality. Notes on general morphological characteristics and flowering periods are also being taken.

The results are to be compared with 1975-1976 data on the 800 plants of the Great Plains source nursery.

There is evident genetic variation in *Agropyron smithii* among the Great Plains sources, some from as far north as Alberta, for color of foliage (waxiness), degree of rhizomatous spread, time and extent of flowering--which may be a latitude/photoperiod response--and percent seed set. Differences were also observed in susceptibility to stem rust (causal organism *Puccinia graminis*) and to ergot (*Calviceps* spp.). Whether these differences are maintained at the Meeker and Fruita plantings remains to be seen. Results may dictate not only the choices of parent plants but also the best location for seed increase of newly synthesized strains.

The results are less complete for the Indian ricegrass nurseries which were established in fall, 1976, and whose characteristics are to be studied in detail in spring, 1977, and subsequent seasons. Additional nurseries will be made as other sources provide adequate seed. A lupine nursery is scheduled for spring, 1977, and establishment in greenhouse pots for flowering, incompatibility testing and other controlled pollinations is currently in progress.

The seed which has been harvested from the older nurseries, and processed to remove empty florets and other inert matter, is material for selection of the parent plant as an elite parent for further breeding manipulation. Characters being surveyed are seed size, relative seedling vigor in optimum germination conditions, and germination response to salinity or other stress tests. These tests for western wheatgrass, Indian ricegrass and lupines are scheduled in the early months of 1977. Seed size ranges are being compiled. For example, among 9 lupine

populations the average weight per seed ranged from 10 to 36 mg with grand mean of 20 mg.

Dormancy breaking treatments are under study for Indian ricegrass. The purpose is to select the most effective treatment of seed for establishing nurseries and seeded trials, as well as breeding for improved germination. The treatment for lupine seeds is mild scarcification of the seed wall followed by soaking so that swollen seed can be planted in pots (the seed for field trials has, of course, to be left dry). A certain proportion of "hard" seed is probably an advantage for reclamation use, however.

Site Seedings

We have sown row-seeding trials in the Piceance Basin involving germplasm sources of all the species listed earlier, except lupines (Table D(A)2). These trials are at the intensive study site (2,042 meters) and at a mountain browse community site (2,438 meters) on areas scraped prior to seeding. Evaluation criteria will be essentially the same as for the nurseries, but will stress emergence, adaptation and survival. Considerable drought stress can be expected from the 1976-1977 winter.

The three types of crownvetch (a Eurasian species) are the three named varieties available in the trade--Penngift, Emerald, and Chemung, which have somewhat different growth habits. The Austrian pea is a legume, not native to this continent either, but adventive in fence rows and waste places, some saline, in the San Luis Valley near Mosca, Hooper, and Alamosa, Colorado. The adaptation of the three species of introduced legumes, including cicer milkvetch, needs testing while we are developing the native, localized strains of lupine and Utah sweetvetch.

Table D(A)2. Seeding trials in the Piceance Basin.

Botanical Name	Common Name	Number of Sources Planted	
		Intensive Site	Mountain Browse Site
Agropyron smithii	Western wheatgrass	25	23
Oryzopsis hymenoides	Indian ricegrass	18	17
Festuca ovina	Sheep fescue	1	1
F. ovina duriuscula	Hard fescue	1	1
Poa pratensis	Kentucky bluegrass	14	27
Cynodon dactylon	Bermuda grass	1	1
Astragalus cicer	Cicer milkvetch	7	7
Coronilla varia	Crownvetch	3	3
Hedysarum boreale utahensis	Utah sweetvetch	1	1
Swainsona salsula	Austrian pea	1	1
	Total	72	82

*Plots were 2 rows, 4.5 x .5 meters apart.

Breeding Procedures

Objective 4 involves the recombination of parent plants whose characteristics and progeny behavior have been measured for at least one or two seasons. Because of the time schedule involved, recombinations cannot be made before the second contract year, and this aspect is therefore treated in the Continuation Proposal.

Seed Multiplication Efficiency Testing

In September, 1976, a seed production trial began at the Fruita Experiment Station. Many different grass species used in revegetation or range seedings were sown; among these were 13 varieties and sources of western wheatgrass, 10 sources of Indian ricegrass, 3 varieties of Kentucky bluegrass, 1 source of sheep fescue, and 1 variety of hard fescue (Table D(A)3). These will be evaluated for establishment and seed production capacities. This trial should also enable us to sharpen our methodology of selecting for plant characteristics that make for good seed production in the breeding nurseries of the target species.

Table D(A)3. Species and varieties seeded at Fruita in September, 1976, for seed production tests.

Botanical Name	Common Name	Variety
Agropyron dasystachyum	Thickspike wheatgrass	Critana
A. desertorum	Crested wheatgrass	Ruff
A. inerme	Bluebunch wheatgrass	p-737
A. spicatum	Beardless bluebunch wheatgrass	Whitmar
A. riparium	Streambank wheatgrass	Sodar
A. smithii	Western wheatgrass	Arriba, Flintlock, Rosana, Mandan 456, + 9 others
A. trachycaulum	Slender wheatgrass	L333
Bouteloua gracilis	Blue grama	Lovington
Bromus inermis	Smooth brome	Lincoln, Manchar
Cynodon dactylon	Bermuda grass	Common
Elymus cinereus	Basin Wildrye	C-43
Eragrostis trichodes	Sand lovegrass	Nebraska 27
Festuca ovina	Sheep fescue	P-274
F. ovina duriuscula	Hard fescue	Durar
F. rubra	Red fescue	#10693
Oryzopsis hymenoides	Indian ricegrass	Paloma + 9 others
Phleum pratense	Timothy	Climax
Poa ampla	Big bluegrass	Sherman
P. compressa	Canada bluegrass	Common
P. pratensis	Kentucky bluegrass	Prato, Nugget, Newport
Sporobulus cryptandrus	Sand dropseed	Native
Stipa viridula	Green needlegrass	P-15637

SUBPROJECT D(B)

ECOLOGICAL-GENETIC VARIATION IN IMPORTANT NATIVE SHRUB SPECIES AND ITS INTEGRATION WITH LANDSCAPE-VEGETATION PATTERNS.

PERSONNEL

Dr. Richard T. Ward, Professor
Dr. Ralph L. Dix, Professor
Dr. William Slauson, Research Associate

TIME EXPENDED BY CO-INVESTIGATORS FOR CURRENT TERM

Dr. Ward--100% time for 1 1/2 months
Dr. Dix--100% time for 1 1/2 months

OBJECTIVES

The contributions basic biology can make to reclamation include: (1) baseline evaluation of genetic variability and potential of particular species for reclamation and (2) baseline definition of the ecological structures to be reclaimed. Such baseline definition, however, is not merely a cataloging and description of vegetation units which are congruent with the management units. Rather, it provides an ecological characterization of the communities within a landscape to be reclaimed in a way which emphasizes the structural and dynamic interrelations of the community. Further, it views the species' populations making up these communities as not necessarily genetically homogeneous. Our approach is twofold: (1) to evaluate the extent of ecotypic (genetic) variation across different populations of selected shrub species by growing representatives from different populations in a common environment and

(2) to develop an abstract gradient model of vegetation structure from original data using standard gradient analysis techniques.

PROGRESS TO DATE

Genetic-ecologic (Ecotype) Differentiation

The ecotype studies are designed to provide a better understanding of the biology of native shrub species, especially concerning the variety of adapted genetic forms, and information about this variation within the context of community and landscape structure. There are two levels of study: (1) ecotypic variation over a broad geographic range and (2) ecotypic variation within a local landscape unit. The first will use materials from Utah, Wyoming, and Colorado, and possibly New Mexico and Arizona. The second and most intensive level of investigation will be to examine ecotypic differentiation among populations collected along local environmental-vegetation gradients within the Piceance Basin.

The general strategy for discovering if variation among populations has a genetic base or is due to plasticity of expression of a common genotype is to grow, in a common environment, materials collected from different populations. Further, it is advisable to use vegetative materials rather than seeds for propagation in the common garden since the vegetative material is certain to be representative of a genotype that is adapted to its environment, while all possible recombinants represented by seed may not be so. Future studies to compare the variation within seed populations with variation in surviving plants are anticipated.

Since the techniques of vegetative propagation of the shrubs selected for study are little known, and since establishment of these

plants takes several years, our early efforts have been directed to learning how to root stem cuttings of the various species. Clippings of the current year's stems were treated with a commercial growth hormone and fungicide, inserted in a perlite medium, and placed under periodic mist in the greenhouse. Species used and results are as follows:

Symphoricarpos oreophilus--Snowberry

rooted in 3 weeks, potted and removed from mist in 8 weeks, alive after 15 weeks

Purshia tridentata--Bitterbrush

rooted in 3 weeks, potted and removed from mist in 8 weeks, alive after 15 weeks

Atriplex canescens--Four-wing Saltbush

rooted in 3 weeks, potted and removed from mist in 8 weeks, alive after 15 weeks

Atriplex confertifolia--Shadscale

rooted in 3 weeks, died at 8 weeks

Cercocarpus montanus--Mountain Mahogany

rooted in 3 weeks, potted and removed from mist in 8 weeks, failing at 15 weeks

Amelanchier alnifolia--Serviceberry

rooted in 7 weeks, potted and removed from mist in 13 weeks, alive after 15 weeks

Quercus gambellii--Gambel's Oak

died before rooting

Prunus virginiana--Choke cherry

died before rooting

Artemisia tridentata--Big Sagebrush

died before rooting

It is expected that use of the earlier softwood rather than the late-season hardwood cuttings and better control of rooting will allow the following schedule for preparation of transplant materials. Collection of softwood shoots and placement in the rooting bench in the greenhouse can be started in late spring. One to two months later, depending on development of roots, the plants can be potted and kept in the greenhouse. They will be ready for transplant in the study garden the following spring, or perhaps earlier if vigorous.

Due to the difficulty and length of time required to establish a garden of shrub species, and anticipating a lengthy period of field measurements before preliminary conclusions concerning shrub ecotypes can be made, the emphasis of the early stage of this study is to establish a variety of shrub species, from a representative range of environments, which will be available for measurements in future growing seasons. The species selected for study are:

Amelanchier alnifolia
Artemisia tridentata
Atriplex canescens
Ceratoides lanata
Cercocarpus montanus
Symphoricarpos oreophilus
Purshia tridentata

The major goal, then, for the first growing season is establishment of these species. In addition we are currently investigating a method of propagating *Symphoricarpos oreophilus* from late fall and winter cutting with the hope of getting some preliminary measurements in the first growing season.

Initially a single common garden for propagation and comparison of different source materials is planned and will be located within the Intensive Study Site in the Piceance Basin. Additional plantings of the studied shrubs will be made at the Meeker Plant Materials Center to be used for replacing damaged or inviable plants in the main garden. Other gardens may be established in the future; however, this is not a pressing need since our experience in other ecotype studies indicates that similar response trends are displayed in multiple gardens.

For each species at least 5 locations from a wide geographic range will be used. The area of interest is indicated in Figure D(B)1. For each of these collection sites, eight different individuals will be represented. Replication for one of the species will be used to test for garden homogeneity. Investigation of ecotypes along a local environmental gradient will initially involve only one or two species, which will be collected from 12-15 sites on a gradient determined in our phytosociological studies.

The specific measurements on the garden material will depend in part on what will be learned about the seasonal cycle and growth habits of each species, and will vary with the species. Measurements to reveal ecotypic differences in phenology, morphology, vigor and growth will be made, and will include the time growth starts, time of leaf expansion, cessation of stem growth, leaf fall, dormancy, leaf size, stem length growth and growth form. For plants which reach reproductive age, the time of flower budding, anthesis, fruit ripening, and seed and fruit characteristics will be measured. In addition, *Artemisia tridentata* and *Ceratoides lanata* strains which are known to differ in palatibility and

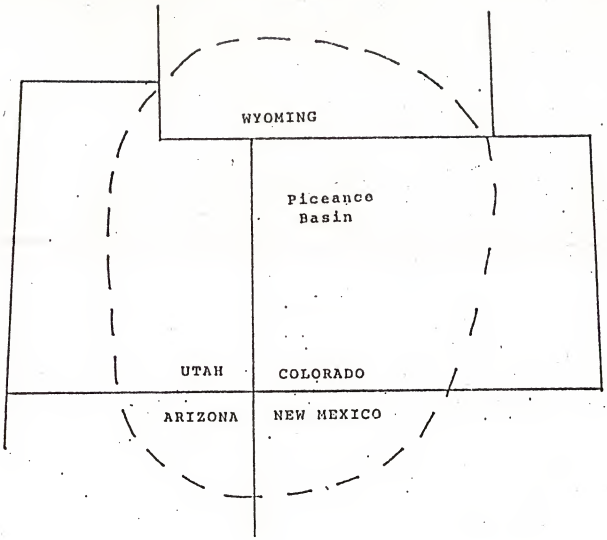


Figure D(B)1. Region of Collection Emphasis for Ecotype Studies.

response to grazing pressure will be maintained for further study of these traits.

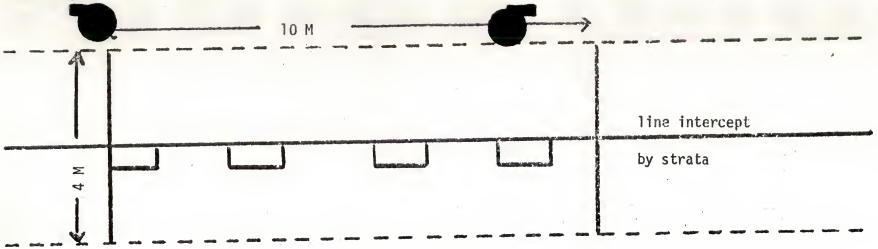
Gradients of Vegetation Structure

Our work to date relates to the phytosociological objectives in two ways. First is the compilation of a standardized floristic list and the initiation of a herbarium of voucher specimens. Second is the development of a sampling regime which will enable comparable treatment of the diverse community types present in the Piceance Basin. Nomenclature of the floristics list follows the usage of Dieter Wilken, Curator of the Colorado State University Herbarium. Names which are different from others in common usage are cross referenced. Verified specimens of the taxa are housed in the CSU Plant Ecology Laboratory, Plant Science Building. Collections by other investigators may be deposited here for verification and voucher reference.

A sampling procedure was developed to sample all the strata of a given community and to provide data appropriate to cross community comparisons even where the communities are of a different life form. The data will be amenable to standard phytosociological techniques of analysis and provide information for structural analysis. In addition environmental measurements will be made which will aid in the interpretation of major axes of variation. These methods are described below.

Stands (areas of homogeneous vegetation) are the basic sampling units. They are kept as small as practical, an average .2 hectares for this study.

The sampling regime consists of three parts: a line intercept to measure shrubs; a set of large area quadrats to measure trees, and a set of small quadrats to measure the understory (Fig. D(B)2). First, a



Area Quadrats

Tree species 4 x 10 quadrats

	Trees Basal areas	Saplings Number	Seedlings Number
Douglas Fir	>10 cms dbh	<10 cms dbh;> 1 m tall	>1 m tall
Aspen	>10 cms dbh	<10 cms dbh;> 1 m tall	>1 m tall
Cottonwood	>10 cms dbh	<10 cms dbh;> 1 m tall	>1 m tall
Pinyon	>2 m tall	<2 m tall	>1 m tall
Juniper	>2 m tall	<2 m tall	>1 m tall

Herb species 0.5 x 1.0 quadrats

Frequency data

Line Intercept

All tree and shrub species by strata (50; 50-150; 150 cms)

Figure D(B)2. Composite Sampling Regime For Tree, Shrub and Herbaceous Species.

steel tape (a 30 m tape was found most useful) is stretched through the stand to form a line. A pole, two meters long and held perpendicular to the tape, is used to project the cover of all shrub species onto the line. The pole is marked with colored tapes at 0.5 m and 1.5 m so that each cover reading can be assigned to one of three strata: below 0.5 m, 0.5-1.5 m and above 1.5 m (Fig. D(B)3). These divisions were selected after field trials indicated that they adequately differentiated various shrubland stands that are dominated by the same shrub species, and will give a measure of the vertical distribution of biomass.

Area quadrats are set out along this line to measure tree and herb species. Tree species are measured in quadrats that are 4x10 m. These quadrats are established by placing the 2 m pole at right angles to the line and moving it along the line for 10 m and repeating the process on the other side of the line. Trees, saplings, and seedlings, as defined in Figure D(B)2, are all counted, and the DBH (diameter breast height) of all trees measured, in these quadrats. The values selected to differentiate trees, saplings, and seedlings were based on field observations that "trees" are in the canopy, "saplings" are small trees that are well established but not mature and that "seedlings" are immature individuals not well established.

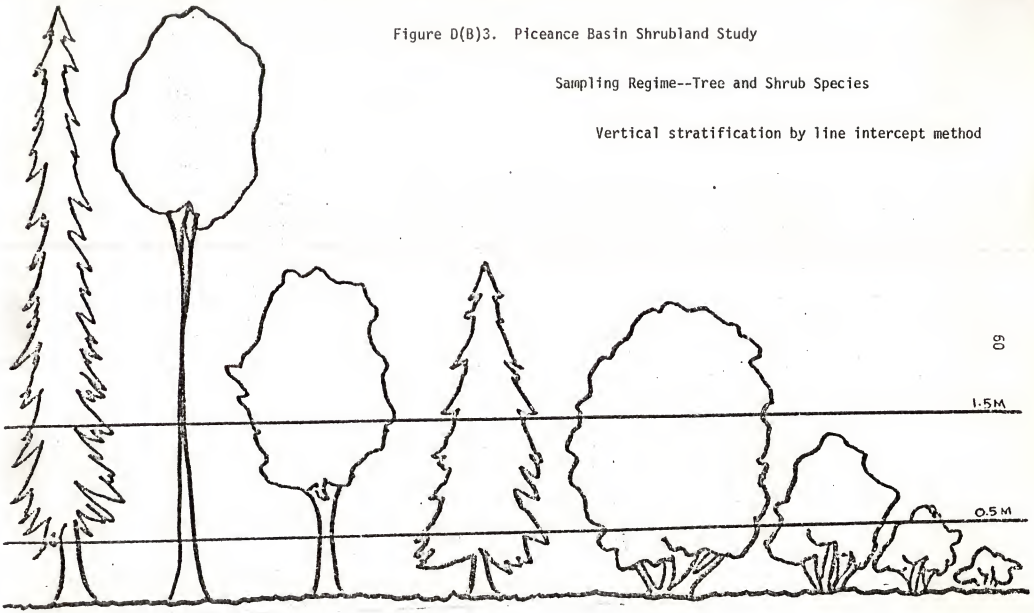
Herbaceous species are sampled in 0.5x1.0 m quadrats placed along the line as illustrated in Figure D(B)2. This will yield frequency data for each species in the understory.

Adequate sample sizes for each method vary greatly from stand to stand, but our tests show that a two man team could complete at least one stand per day in the most difficult types (tall shrublands) and up to four stands per day in the least difficult (low shrublands).

Figure D(B)3. Piceance Basin Shrubland Study

Sampling Regime--Tree and Shrub Species

Vertical stratification by line intercept method



Environmental measurements and estimates are limited to those which can be taken in any stand on any day. No permanent, long term equipment will be installed. The values to be recorded are: slope, exposure, elevation, slope position, parent material, soil depth, soil texture, soil structure (blocky vs. granular), soil color (dark, medium, light) and lime layer (depth). These basic measurements and estimates can be combined into various scalars for further analysis.

Standard methods of gradient analysis will be applied to the data but at this time it is not possible to predict which specific method may be most applicable. Direct gradient analysis methods will be employed as a first approach to analysis and interpretation but, if these prove inadequate, indirect methods will be used.

Discussion

One general goal of these studies is to provide background information on genetic variability enabling reclamationists to address knowledgably the problem of selecting organisms for planting. If an area is to be reclaimed with native species, the question of "What is native?" has to be answered. At one extreme, it may turn out that only small local populations of the desired species can be considered to have the genetic material necessary for successful growth on land to be reclaimed. On the other extreme, perhaps any representatives of a species from a wide geographic range will be adequate to supply propagation material.

There are some biological considerations that address this problem in general. If ecotypic differentiation has taken place within a given species this means that the different populations are differentially adapted to specific environmental situations within the range of the

species. In these instances use of local material for reclamation would be optimal. An exception could occur where a reclaimed environment was so changed that local populations were not fit for it but were more suitable for distant ecotypes. However, such modified situations are unpredictable due to the complexities of ecotypic variation, the underlying selective pressures, and the total interactive milieu of organism with organism and organism with environment. Prudence therefore directs our research toward maximal use of locally evolved and established ecotypes to reclaim situations which are restructured to the pre-reclamation conditions. To put this another way, the experiments of evolutionary processes which result in adapted ecotypes have already been performed. The challenge, then, is to interpret and use the results of these natural "experiments" to the best advantage for reclamation.

SUBPROJECT E

INTERACTION AMONG PLANT SPECIES, SOIL MATERIAL, CULTURAL PRACTICES, AND ENVIRONMENTAL PARAMETERS ON PLANT COMMUNITY ESTABLISHMENT AND RATE AND DIRECTION OF SECONDARY SUCCESSION

PERSONNEL

Dr. C. Terwilliger, Jr., Professor
Mr. David A. Koehler, Research Associate
Mr. Douglas E. Johnson, Graduate Research Assistant

TIME EXPENDED BY CO-INVESTIGATOR FOR CURRENT TERM

Dr. Terwilliger--100% for .5 months

OBJECTIVES

1. To determine the proper reseeding practices for potentially usable plant species and mixtures of plant species and their relationship to cultural practices and inputs.
2. To determine the rate and direction of plant community succession as influenced by: (a) mixtures of species used in revegetation, (b) cultural practices, and (c) soil conditions.
3. To determine allelopathic interaction, if any, which may affect rate and direction of succession.
4. To develop information and guidelines for increasing the successful germination and establishment of important native plants.

PROGRESS TO DATE

Revegetation Technique Plot

At the intensive study site, vegetation was removed from an area totalling approximately 1.9 hectares. Within this area were located six subplots measuring 17x92.5 m. For each test plot, topsoil and subsoil were removed to a 1 m depth by using a 25 cu. meters capacity self-loading scraper aided by a D-8 caterpillar. During the process of ripping and scraping, the earthen material was thoroughly mixed.

Soils from the first subplot were removed, mixed, then stockpiled. Subsequently, soils removed from each successive subplot were replaced in the preceding excavation. When the sixth and final subplot was excavated, the stockpiled material from the initial subplot was utilized to fill it. Since the swell factor of excavated soil material was near zero, no excess material needed to be disposed of. To firm the seedbed, a D-8 caterpillar tractor was "walked" across the plots. This process compacted the loose and dry surface, enabling seeding depth to be more accurately regulated.

Within the six subplots, 24 sub-subplots were located, each measuring 6x8 m. These were separated by a 1.5 m buffer zone and marked with wooden stakes.

The northernmost three subplots will receive supplementary water applications, the remaining three will not. Each of the 24 separate units within the subplots was subjected to three additional levels of treatment. The combinations of the various treatments and the configuration of the subplots are shown in Figure E1. The treatments indicated were as follows:

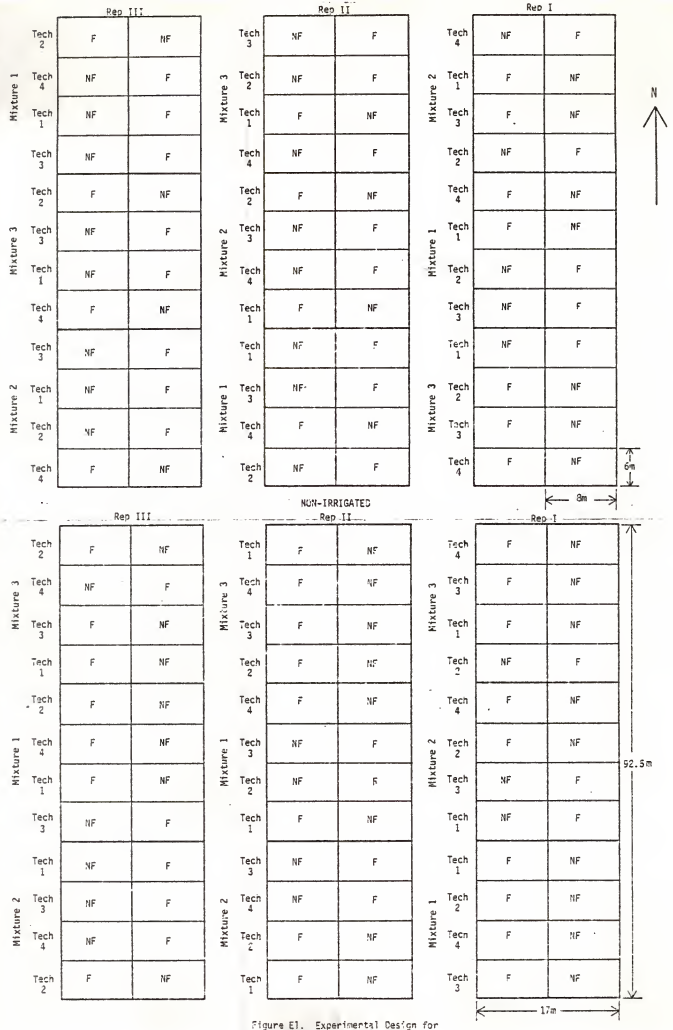


Figure E1. Experimental Design for Revegetation Technique Plot

a. Fertilization

F --fertilized, 100# N, 80# P

NF--non-fertilized

b. Seeding technique

Techinque 1--Drill seed entire mixture, seed grasses and forbs at 1/2 inch and shrubs at 3/4 to 1 inch.

Technique 2--Drill seed entire mixture, seed grasses and forbs at 1/2 inch and shrubs at 3/4 to 1 inch. Decrease seeding rate of grasses and forbs, increase seeding rate on shrubs.

Technique 3--Drill seed grasses and forbs, transplant shrubs following year.

Technique 4--Broadcast seed grasses and forbs, transplant shrubs following year.

c. Seeding mixtures

Mixture 1--Combination, native and introduced species.

1.	Nordan crested wheatgrass	*Agropyron cristatus*
2.	Siberian wheatgrass	*A. sibiricum*
3.	Critana thickspike wheatgrass	*A. dasystachyum*
4.	Sodar streambank wheatgrass	*A. riparium*
5.	Slender wheatgrass	*A. trachycaulum*
6.	Regar meadow brome	*Bromus erectus*
7.	Indian ricegrass	*Oryzopsis hymenoides*
8.	Green needlegrass	*Stipa viridula*
9.	Durar hard fescue	*Festuca ovina duriuscula*
10.	Madrid yellow sweetclover	*Melilotus officinalis*
11.	Utah sweetvetch	*Hedysarum boreale utahensis*
12.	Globemallow	*Sphaeralcea munroana*
13.	Lewis flax	*Linum lewisii*
14.	Arrowleaf balsamroot	*Balsamorhiza sagittata*
15.	Fourwing saltbush	*Atriplex canescens*
16.	Stansbury cliffrose	*Cowania mexicana stansburiana*
17.	Winterfat	*Ceratoides lanata*
18.	Green ephedra	*Ephedra viridis*

Mixture 2--Native species

1.	Rosana western wheatgrass	*Agropyron smithii*
2.	Sodar streambank wheatgrass	*A. riparium*
3.	Bearded bluebunch wheatgrass	*A. spicatum*
4.	Indian ricegrass	*Oryzopsis hymenoides*
5.	Green needlegrass	*Stipa viridula*
6.	Durar hard fescue	*Festuca ovina duriuscula*
7.	Shermans' big bluegrass	*Poa ampla*
8.	Alkali sacaton	*Sporobolus airoides*
9.	Globemallow	*Sphaeralcea munroana*
10.	Utah sweetvetch	*Hedysarum boreale utahensis*
11.	Palmer penstemon	*Penstemon palmeri*
12.	Stansbury cliffrose	*Cowania mexicana stansburiana*
13.	Green ephedra	*Ephedra viridis*
14.	Fourwing saltbush	*Atriplex canescens*
15.	Winterfat	*Ceratoides lanata*
16.	Antelope bitterbrush	*Purshia tridentata*

Mixture 3--Introduced species

1.	Nordan crested wheatgrass	*Agropyron cristatum*
2.	Siberian wheatgrass	*A. sibiricum*
3.	Jose tall wheatgrass	*A. elongatum*
4.	Luna pubescent wheatgrass	*A. trichophorum*
5.	Oahe intermediate wheatgrass	*A. intermedium*
6.	Manchar smooth brome	*Bromus inermis*
7.	Regar meadow brome	*B. erectus*
8.	Vinal Russian wildrye	*Elymus junceus*
9.	Ladak alfalfa	*Medicago sativa*
10.	Madrid yellow sweetclover	*Melilotus officinalis*
11.	Lutana cicer milkvetch	*Astragalus cicer*
12.	Sainfoin	*Onobrychis viciaefolia*
13.	Bouncing bet	*Saponaria officinalis*
14.	Small burnet	*Sanguisorba minor*
15.	Siberian peashrub	*Caragana arborescens*
16.	Russian olive	*Elaeagnus angustifolia*

Successional Studies

Plots have been established in the intensive study area that will indicate the rate and direction of vegetative succession. Studies on these plots will demonstrate the suitability of various seeded mixtures, fertilizer treatments, and mulch treatments for establishing a stable community of an advanced seral stage. A total area encompassing 2.2 hectares was stripped of vegetation and ripped to a depth of 30 cm.

Some topographic restructuring was necessary to prevent runoff and erosion problems. Soil from the sides was used to raise the center (on a north-south line). After shaping and ripping, the plot was backbladed to smooth the surface.

Within the plot, 108 sub-subplots were situated (Fig. E2). Each measures 9x18 m, with a 1.5 m buffer zone between. Each was marked by 16-inch wooden stakes at the corners. The treatments applied were as follows: mulch and no mulch, three fertilization levels, and six species mixtures--all replicated three times. The first treatment (mulching) was non-random owing to the inability of the hydromulcher to reach the plot center without disturbing outer sub-subplots. The latter two treatments were both randomized. Only the phosphorus fertilizer was applied this fall. It was broadcast on the surface, then rototilled and mixed with the soil to a 30 cm depth so as to be available at the site of root-soil interchange. Nitrogen, which is much less permanent in soil, will be applied in the spring after germination has occurred.

A. Mulching

The mulch treatments consisted of Silvafiber hydro mulch applied at a one ton/acre rate and the unmulched controls.

B. Fertilizer treatments

1. 100 pounds nitrogen, 50 pounds phosphorus per acre
2. 50 pounds nitrogen, 25 pounds phosphorus per acre
3. control (0 pounds nitrogen, 0 pounds phosphorus per acre)

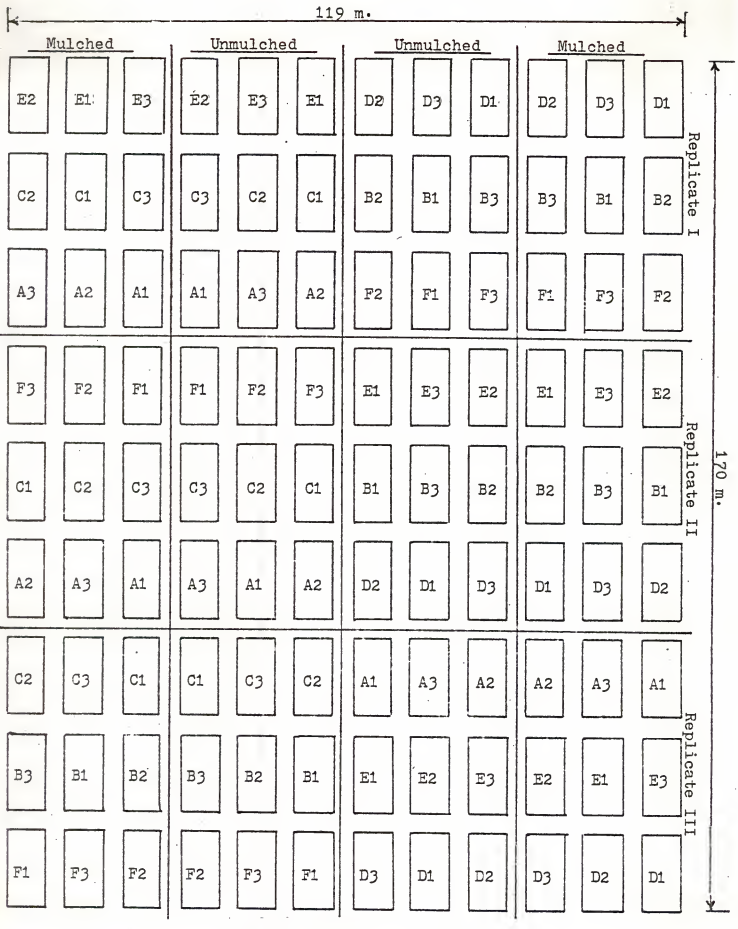

119 m.
170 m.
Mulched
Unmulched
Unmulched
Mulched
Replicate I
Replicate II
Replicate III
E2 E1 E3 E2 E3 E1 D2 D3 D1 D2 D3 D1
C2 C1 C3 C3 C2 C1 B2 B1 B3 B3 B1 B2
A3 A2 A1 A1 A3 A2 F2 F1 F3 F1 F3 F2
F3 F2 F1 F1 F2 F3 E1 E3 E2 E1 E3 E2
C1 C2 C3 C3 C2 C1 B1 B3 B2 B2 B3 B1
A2 A3 A1 A3 A1 A2 D2 D1 D3 D1 D3 D2
C2 C3 C1 C1 C3 C2 A1 A3 A2 A2 A3 A1
B3 B1 B2 B3 B2 B1 E1 E2 E3 E2 E1 E3
F1 F3 F2 F2 F3 F1 D3 D1 D2 D3 D2 D1

Figure E2. Experimental Design for Plant Successional Plot.

C. Seeding mixtures

1. Native grass mixture

	Seeding Rate (PLS)
Wheatgrass, beardless bluebunch	3 lbs/acre
Wheatgrass, western (Rosana)	4 lbs/acre
Needlegrass, green	3 lbs/acre
Ricegrass, Indian	2 lbs/acre
Wheatgrass, streambank (Sodar)	3 lbs/acre

2. Introduced grass mixture

Wheatgrass, crested (Nordan)	3 lbs/acre
Wheatgrass, pubescent (Luna)	4 lbs/acre
Wildrye, Russian (Vinal)	3 lbs/acre
Wheatgrass, intermediate (Oahe)	4 lbs/acre

3. Native grass-forb mixture

Wheatgrass, thickspike (Critana)	3 lbs/acre
Needlegrass, green	2 lbs/acre
Wheatgrass, beardless bluebunch	2 lbs/acre
Ricegrass, Indian	1 lbs/acre
Wheatgrass, streambank (Sodar)	2 lbs/acre
Sweetvetch, Utah	1 lbs/acre
Crownvetch, Emerald	1 lbs/acre
Flax, Lewis	1 lbs/acre
Penstemon, Palmer	1 lbs/acre

4. Introduced grass-forb mixture

Wildrye, Russian (Vinal)	3 lbs/acre
Wheatgrass, crested (Nordan)	3 lbs/acre
Wheatgrass, pubescent (Luna)	3 lbs/acre
Alfalfa (Ladak)	1 lbs/acre
Bouncing-bet	1 lbs/acre
Burnet, small	1 lbs/acre
Milkvetch, Cicer (Lutana)	2 lbs/acre

5. Native grass-forb-shrub mixture

Ricegrass, Indian	2 lbs/acre
Wheatgrass, beardless bluebunch	2 lbs/acre
Wheatgrass, western (Rosana)	3 lbs/acre
Crownvetch emerald	1 lbs/acre
Sweetvetch, Utah	1 lbs/acre
Cliffrose, Stansbury	1 lbs/acre
Ephedra, green	1 lbs/acre
Saltbush, fourwing	2 lbs/acre
Winterfat, common	1 lbs/acre

6. Native and introduced grass-forb-shrub mixture

Needlegrass, green	2 lbs/acre
Wheatgrass, beardless bluebunch	2 lbs/acre
Wheatgrass, crested (Nordan)	2 lbs/acre
Wheatgrass, pubescent (Luna)	2 lbs/acre
Milkvetch, Cicer (Lutana)	1 lbs/acre
Sweetvetch, Utah	1 lbs/acre
Cliffrose, Stansbury	1 lbs/acre
Ephedra, green	2 lbs/acre
Winterfat, common	1 lbs/acre

Annual Disturbance Plot

These are small subplots, measuring 6x9 m, subjected to various degrees of disturbance. No reclamation measures have been implemented. Natural succession and invasion from peripheral plant communities will be the mechanisms dictating which plant species eventually establish there.

Two replications of the following four treatments of increasing severity were constructed (Fig. E3):

(1) Vegetation was removed by scraping with the blade of a caterpillar type tractor. Care was taken to leave as much topsoil as possible.

(2) After removing the vegetation by scraping, the subsoil was ripped and mixed to a 30 cm depth.

(3) After scraping off surface vegetation, a front-end loader was utilized to remove topsoil and subsoil to a 1 m depth. After mixing, the material was replaced in the same area.

(4) After vegetation was scraped off, the top 1 m of topsoil and subsoil was removed and stockpiled. Then, a second 1 m layer of subsoil was removed and stockpiled. The two layers were then replaced in reverse order, with the deeper layer placed on top.

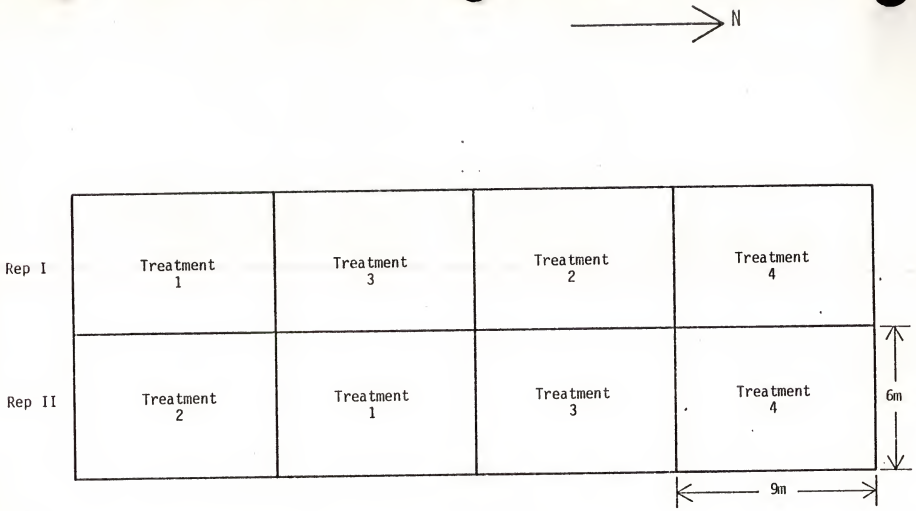


Figure E3. Experimental Design for Annual Disturbance Plot.

SUBPROJECT F

IMPORTANCE OF MYCORRHIZAL FUNGI

PERSONNEL

Dr. F. Brent Reeves, Jr., Associate Professor
Mr. Tom Moorman, Research Assistant
Ms. Jean Kiel, Research Assistant
Mr. David Wagner

TIME EXPENDED BY CO-INVESTIGATOR FOR CURRENT TERM

Dr. Reeves--100% time for 1.5 months

OBJECTIVES

In most natural ecosystems the plants grow in an environment of tremendous microbial activity. Around the roots of plants the most common association is a symbiosis between a fungus and a plant root--a mycorrhiza. Research has demonstrated that the mychorrhizal association benefits the host in both its development and growth. In particular, enhanced uptake of soil elements, particularly phosphorus, increased resistance to drought, and greater biomass of mycorrhizal vs. non-mycorrhizal individuals has been shown for many different plants. For most plants the mycorrhizal association appears to be an absolute rule and non-mycorrhizal plants are the rare exception. However, a few common families of plants typically lack any mycorrhizae, viz. the Cyperaceae, Polygonaceae, Chenopodiaceae, Amaranthaceae, Caryophyllaceae, and Brassicaceae.

In reading the results of Surface Rehabilitation of Land Disturbances Resulting from Oil-Shale Development (Cook, 1974) the observation that most of the plants which invaded the disturbed land were members of the above mentioned non-mycorrhizal families was surprising in view of the fact that most plants are mycorrhizal. Table F1 indicates the most common non-mycorrhizal plants found in the area following disturbance. The abundance of non-mycorrhizal plants which invade disturbed sites in the semi-arid regions of Colorado is in sharp contrast to the results reported for successful plants colonizing mining spoils in the more mesic environments of the east (Pennsylvania) and in Scotland. In fact the suggestion that "mycorrhizal infection may be essential for the survivial of most of the herbaceous plants" was based on the examination of successful plants from Pennsylvanian and Scottish mine spoils.

The hypothesis that delays in the reclamation of disturbed habits to their former relationships may, in part, lie with the mycorrhizal associations was then formulated. The purpose for the initiation of this study was to examine the role of mycorrhizae in secondary succession on disturbed lands in Colorado's oil shale region.

PROGRESS TO DATE

The test of our hypothesis was begun with a survey of the more common plants in the oil shale region to determine which were and which were not mycorrhizal. Our initial objective was to collect the most common plants on both a disturbed and an adjacent undisturbed area near the planned intensive research site. A suitable area was found within Sec. 4, T2S, R98W, only one-quarter mile northeast of the intensive study site. The communities found here were Pinyon-Juniper and Sagebrush. Adjacent

Table F1. Plants occurring on disturbed ecosystems in Colorado's oil shale region.

Low elevation ecosystems--reseeded with Crested wheatgrass (*Agropyron cristatum*)		
1st year	51%	Russian thistle (*Salsola kali*)*
	23%	Crested wheatgrass (*Agropyron cristatum*)
	11%	Indian ricegrass (*Oryzopsis hymenoides*)
8th year	48%	Crested wheatgrass (*Agropyron cristatum*)
	17%	Russian thistle (*Salsola kali*)*
Low elevation ecosystems--not reseeded with Crested wheatgrass		
1st year		Russian thistle (*S. kali*)*
	48%	Lambsquarters (*Chenopodium album*)*
		Miner's candle (*Cryptantha sericea*)
	8%	Native grasses
	34%	Indian ricegrass (*O. hymenoides*)
High elevation ecosystems--reseeded with Crested wheatgrass (but failed to grow)		
1st year	50%	Russian thistle (*S. kali*)*
	22%	Indian ricegrass (*O. hymenoides*)
	12%	Beardless wheatgrass (*Agropyron inerme*)
8th year	15%	Crested wheatgrass (*A. cristatum*)
	9%	Beardless wheatgrass (*A. inerme*)
	40%	Big sagebrush (*Artemisia tridentata*)
		Knotweed (*Polygonum aviculare*)*
	17%	Stickseed (*Lappula redowskii*)
		Dandelion (*Taraxacum officinale*)
Bottomland sagebrush ecosystem--reseeded with Crested wheatgrass		
1st year	99%	Crested wheatgrass (*A. cristatum*)
8th year	24%	Crested wheatgrass (*A. cristatum*)
	10%	Cheatgrass (*Bromus tectorum*)
	43%	Rubber rabbitbush (*Chrysothamnus nauseosus*)
		Greasewood (*Sarcobatus vermiculatus*)*
		Pepperweed (*Lepidium* spp.)*
	prominent	Lambsquarters (*C. album*)
		Stickseed (*L. redowskii*)
Bottomland sagebrush ecosystem--not reseeded with Crested wheatgrass		
1st year	99%	Russian thistle (*S. kali*)*
	1%	Lambsquarters (*C. album*)*

*Indicates genera in families reported to be non-mycorrhizal.

to these communities was an old roadbed which had been disrupted with 30 cm rippers two years earlier. The vegetation on this disturbed site included the species previously reported to invade disturbed sites in this region.

The comparisons of the data from the undisturbed vs. disturbed site indicate that our hypothesis must be studied carefully (Table F2). The complete lack of mycorrhizae on the disturbed site becomes particularly striking when a tabulation of the species sampled shows that 87% of the species in the adjacent undisturbed habit, less than 15 feet away, are mycorrhizal. That 100% of the plants from the disturbed site lack any mycorrhizae strongly supports our hypothesis that conditions for mycorrhizal formation are so altered that the adjacent native plants were unable to reestablish seedlings in the disturbed area.

Further checks on the relative presence of potential mycorrhizal spores in the two soils were designed. A bioassay using corn (*zea mays*) as the test host was employed. Corn was chosen for two basic reasons. One, it has the widest range of any plant known for hosting many different species of mycorrhizal fungi and therefore would serve as a more sensitive indicator. Two, corn has a short life cycle with rapid growth and therefore the experiments would yield results rapidly.

The methods employed in this bioassay were as follows. Pots (10 cm) were sterilized (soaked in 10% Chlorox for 10 minutes and washed) and then filled with a soil-perlite-vermiculite-sand mixture. The perlite, vermiculite, and sand were autoclaved and mixed 1:1:1 (Volume). Soil from either the disturbed or undisturbed site was mixed with the perlite-vermiculite-sand mixture in a 1:3 (Volume) ratio (0.25 in Fig. F1) or in a 0.3:3 (Volume) ratio (0.1 in Fig. F1). Controls were

Table F2. Presence (M+) and absence (M-) of mycorrhizae.

Undisturbed Dump Site		Disturbed Site	
Chenopodiaceae		**Chenopodiaceae**	
Ceratoides lanata	M+	*Atriplex argentea*	M-
Sarcobatus vermiculatus	M-	*A. confertifolia*	M-
		A. rosea	M-
		Chenopodium album	M-
		C. leptophyllum	M-
		Sarcobatus vermiculatus	M-
		Salsola kali	M-
Brassicaceae		**Brassicaceae**	
		Descurania pinnata	M-
		Lepidium perfoliatum	M-
		Physaria acutifolia	M-
Polygonaceae		**Polygonaceae**	
Eriogonum effusum	M+	*Erigonum cernuum*	M-
E. lonchophyllum	M+	*Polygonum aviculare*	M-
Compositae		**Compositae**	
Artemisia tridentata	M+		
Chrysothamnus nauseosus	M+		
Gutierrezia sarothrae	M+		
Haplopappus nuttallii	M+		
Malvaceae		**Malvaceae**	
Sphaeralcea coccinea	M-	*Sphaeralcea coccinea*	M-
Leguminosae			
Astragulus diversifolia	M+		
A. purshii	M+		
Hedysarum boreale	M+		
Rosaceae			
Purshia tridentata	M+		
Polemoniaceae			
Phlox hoodii	M+		
Scrophulariaceae			
Penstemon spp.	M+		

Table F2.--Continued

Gramineae	
Agropyron smithii	M+
A. inerme	M+
Koeleria cristata	M+
Oryzopsis hymenoides	M+
Stipa spp.	M+
Pinaceae	
Pinus edulis	M+
Cupressaceae	
Juniperus utahensis	M+

sterilized soil from both sites mixed at the same ratios. Surface sterilized corn was then planted in these soil mixtures.

The results of these experiments are shown in Figure F1. In only 30 days in both the 0.1 and 0.25 soil mixture from the undisturbed site (U in diagram) the corn was 100% mycorrhizal. However, 60 days were required for corn to become mycorrhizal in the 0.25 soil mixture from the disturbed site, and 90 days were required for mycorrhizae to develop in 0.1 soil mixture from the disturbed site (D in the diagram). The controls remained non-mycorrhizal throughout the experiment.

Our interpretation of these results is that the disturbed soil definitely contains viable mycorrhizal spores but they probably occur in such low numbers that long periods of time are required before infection in the host plant occurs. This delay in infection may account for the delay in the establishment of native plants which are typically mycorrhizal and may require mycorrhizae for survival. Since "ideal" plant establishment conditions with proper temperature and soil moisture conditions are rare or of short duration in arid and semi-arid environments, mycorrhizal limitations may actually be the cause of unsuccessful rehabilitation attempts.

Because current methods of determining relative numbers of mycorrhizal spores and their viability have not been worked out, we chose to sample the saprobic fungi from both the disturbed and undisturbed sites at two depths (6-8 and 18-20 cm) to determine if differences existed in the numbers and kinds of organisms. The procedure used as a standard dilution plate technique using Martin's medium. Our preliminary results are given in Figure F2. As expected, the numbers of saprobic fungi decrease with the increasing depth in the natural, undisturbed ecosystem.

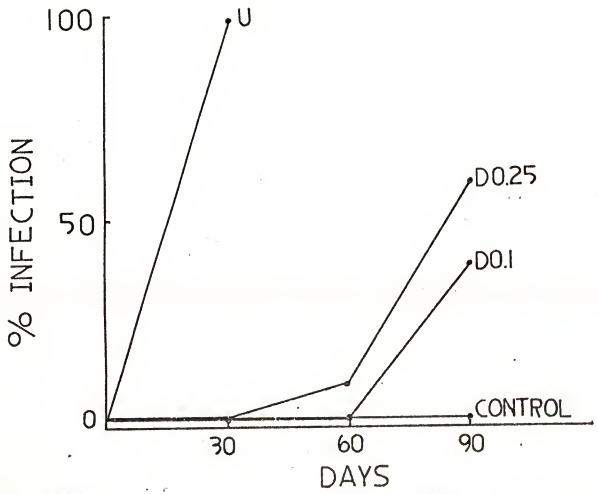


Figure F1. Per Cent Mycorrhizal Infection in Corn Grown in Disturbed (D) and Undisturbed (U) Soil.

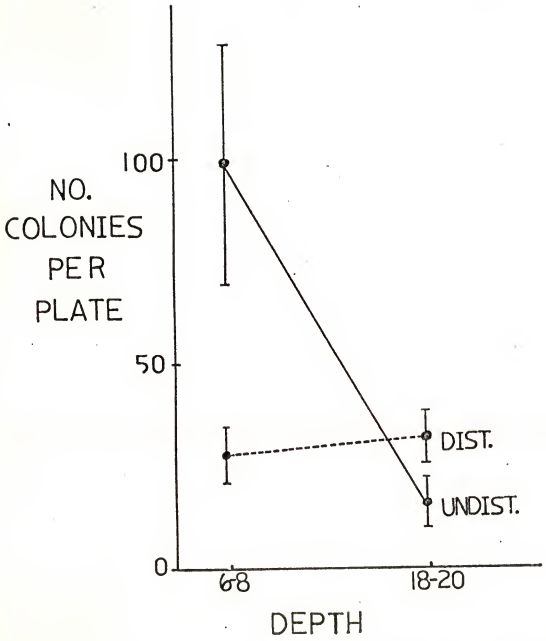


Figure F2. Number of Saprobic Fungi Isolated From Disturbed and Undisturbed Soil

Quite a different situation occurs on the disturbed soil. There appears to be no significant difference in the numbers of saprobic fungi with increasing depth, but we suspect that great variations in species composition occurs. These results must be repeated and checked.

The reduced numbers of saprobic fungi may reflect the situation for the mycorrhizal fungi. In fact, because there is a lack of suitable hosts for the mycorrhizal fungi, their respective numbers may be reduced even more than was observed for the saprobic fungi. The supposed change in species composition in the disturbed habit may also be important in establishing new microbiological relationships with the root environment. Very limited studies elsewhere suggest that in certain cases a change in the microbiological relationships resulting from disturbance may lead to the greater success of potentially parasitic fungi which, in turn, may selectively destroy the seedlings of the native vegetation. At this point this must remain an hypothesis. We have absolutely no data to support this suggestion.

APPENDIX I

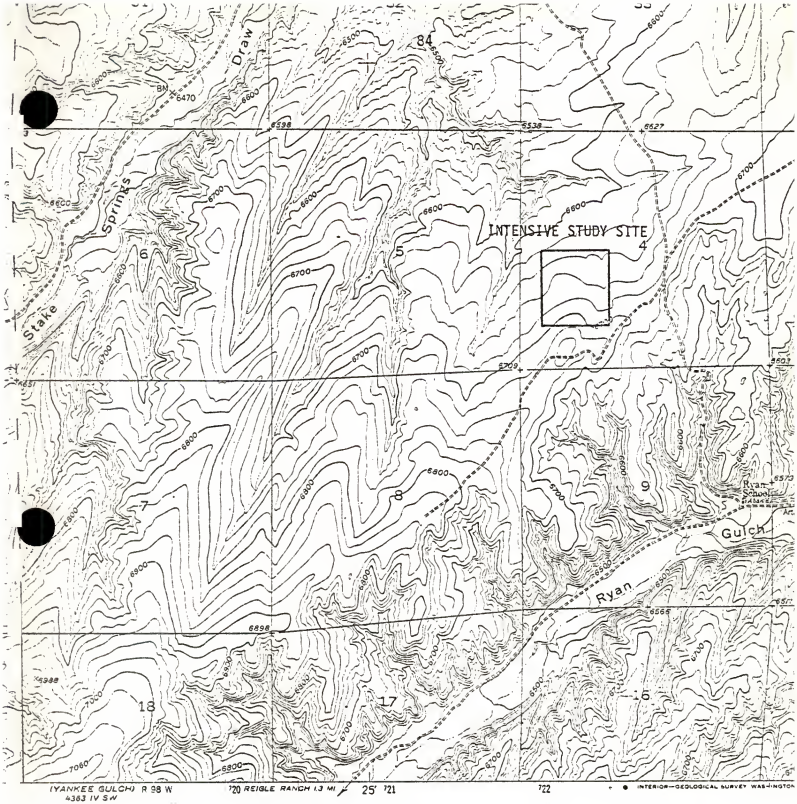


Figure 1. Location of Intensive Study Site

Table 1. List of Species Encountered on the Intensive Study Area in August, 1976

Species	Common Name	Symbol	Sagebrush	Pinyon-Juniper
Agropyron inerme (Scribn. + Smith) Rydb.	Beardless bluebunch wheatgrass	Agin 1	X	X
A. smithii	Bluestem wheatgrass	Agsm	X	X
A. trachycaulum	Slender wheatgrass	Agtr 1	X	X
Bouteloua gracilis	Blue grama	Bogr		X
B. hirsuta	Hairy grama	Bohi		X
Bromus tectorum	Cheatgrass brome	Brte 1	X	
Festuca arizonica	Arizona fescue	Fear 1	X	X
Koeleria cristata	Prairie junegrass	Kocr	X	X
Oryzopsis hymenoides	Indian ricegrass	Orhy	X	X
Poa fendleriana	Mutton bluegrass	Pofe	X	X
P. sandbergii	Sandberg bluegrass	Posa 1	X	X
Sitanion hystrix	Bottlebrush squirreltail	Sihy	X	X
Stipa comata	Needle and thread	Stco 1	X	X
Carex geyeri	Elk sedge	Cage 1	X	X
Antennaria rosea	Greene rose pussytoes	Anro		X
Aster spp.		ASTE	X	X
Astar arenosus	Michaelmas daisy	Asar		X
Astragalus diversifolius	Gray fineleaf astragalus	Asdi		X
A. purshii	Pursh loco	Aspu	X	
Chaenactis alpina	Alpine chaenactis	Chal 1	X	
C. douglasii	Douglas chaenactis	Chdo		X
Chenopodium spp.	Goosefoot	CHEN		X
Cryptantha scricea	Miner's candle	Crse	X	X
Descurainia spp.	Tansy mustard	DESC 1	X	X
Erigeron spp.	Fleabane daisy	ERIG		X
Eriogonum alatum	Wing eriogonum	Eral		X
E. lonchophyllum	Spearleaf eriogonum	Erlo 1		X
Euphorbia fendleriana	Fendler's spurge	Eufe		X
Haplopappus spp.	Goldenweed	HAPL		X
Haploppapus acaulis Nutt.	Stemless goldenweed	Haac	X	X
H. nuttallii	Nuttall goldenweed	Hanu	X	X
Hymenoxys richardsonii	Pingue (do. rubberweed)	Hyri		X
Ipomopsis aggregata	Skyrocket gilia	Ipag	X	
I. congesta	Bullhead gilia	Ipco	X	X
Leptodactylon pungens	Prickly phlox	Lepu		X
Oxytropis lambertii	Cozy weed	Oxla		X
Penstemon spp.	Penstemon	PENS	X	X
P. caespitosus	Mat penstemon	Peca		
Phlox hoodii	Richards hoods phlox	Phho	X	X
P. longifolia Nutt.	Longleaf phlox	Phlo		X
P. multiflora	Flowery phlox	Phmu	X	X
Physaria floribunda	Twinpod	Phfl		X
Senecio multilobatus	Lobeleaf groundsel	Semu		X
Sisymbrium altissimum	L. tumblemustard	Sial		X
Sphaeralcea coccinea	Scarlet globemallow	Spco 1	X	X
Townsendia spp.	Townsendia	TOWN		X
Trifolium gymnocarpon Nutt.	Hollyleaf clover	Trgy	X	X
Artemisia tridentata Nutt.	Big sagebrush	Artr	X	X
Chrysothamnus nauseosus	Rubber rabbitbush	Chna	X	X
C. viscidiflorus Nutt.	Douglas rabbitbush	Chvi 3	X	
Gutierrezia Sarothrae	Broom snakeweed	Gusa	X	X
Juniperus osteosperma	Little Utah juniper	Juos		X
Opuntia fragilis Nutt.	Brittle pricklypear	Opfr	X	X
O. polyacantha	Plains pricklypear	Oppo	X	X
Pinus edulis	Engelm pinyon	Pied		X
Sarcobatus vermiculatus	Black greasewood	Save 2	X	
Tetradymia canescens	Gray horsebrush	Teca	X	X

Table 2. % Frequency in m^2 Quadrats

Species	1	2	3	4	5	6	7	8	9	10	Mean Frequency	11	12	13	14	15	16	17	18	19	20		Grand Mean
Agin 1	40	20			40	40		20	20		18.0										20	2.0	10.0
Agsm									20		2.0		80	100	20	100	20	60	60	80	100	62.0	32.0
Agtr	40	20	60	60	20	80	60	100	40	40	52.0		60			20	20					10.0	31.0
Bogr									20		2.0												1.0
Brte 1											0					20		40	100			16.0	8.0
Fear 1									20		2.0			40		20			20			8.0	5.0
Kocr	20		20		20	20	40	20	60	40	24.0	40	60	60	60	40	20			20	20	32.0	28.0
Orhy	60	60	40	100	40	60	20	20	20	60	48.0	100	40	40	40	60	100	20		60		46.0	47.0
Pafe	20		20								4.0				20				20		20	6.0	5.0
Posa 1	20	40	20				20		40	40	18.0	20	60	100	40	40	60	20	40	60	60	50.0	34.0
Sihy	40		20		20						8.0	60	80		60	40	40	80	80	20	40	50.0	29.0
Stco 1	100	40	60	20	80	40			20	80	44.0	40	40	80	100	80	20		20	80	100	55.0	50.0
Cage 1									20		2.0				20							2.0	2.0
Anro								40			4.0												2.0
ASTE	40		20		20	20		20	60	40	22.0			20	40	20			20	20	40	16.0	19.0
Asdi										60	6.0												3.0
Aspu																20				20		4.0	2.0
Chal 1																		20				2.0	1.0
CHEN	40										4.0												2.0
Crse	100	80	100	60	60	80	40	60	40	20	64.0						40					4.0	34.0
OALE															20							2.0	1.0
OESC					20						4.0							40				4.0	4.0
ERIG	20										2.0												1.0
Eral		20									2.0												1.0
Erlo 1		20									2.0												1.0
Eufe						40					4.0												2.0
HAPL			20								2.0												1.0
Haac				40		20					6.0	20		20								4.0	5.0
Hanu	40	40			20	40	20	20	20	20	22.0	20				20					20	6.0	14.0
Hyri		20									2.0												1.0
Ipaq														20								2.0	1.0
Ipco	20	60	40	80		20	60	40	60	20	40.0	20											2.0
Lepu							20	20			4.0												21.0
Oxla				20						20	4.0												2.0
PENS									20		2.0						20			20		4.0	3.0
Phho	80	40	40	40	40	20	20	20	60	80	44.0	100	80	100	80	80	100			80	60	68.0	56.0
Phlo		40	20	40	20	20					14.0												7.0
Phmu						20	80	20			12.0									20		2.0	7.0
Phfl	20			20		60	40	20		20	18.0												9.0
Semu			60	80	20	40	20	20	60	80	38.0												19.0
Sial					20						2.0												1.0
Spco 1	20								60		8.0		60	40	40		40	20		40	60	30.0	19.0
TOWN							40		40		8.0												4.0
Trgy									20	20	4.0			40	20						20	8.0	6.0
Artr	80	40	40	20	40	60		60	60	40	44.0	80	80	80	100	100	100	100	100	60	100	90.0	67.0
Chna									40		4.0												2.0
Chvl 3																	40					4.0	2.0
Gusa			40		40	40	60	20		60	26.0	20						20		40	20	10.0	18.0
Juos									20	20	4.0												2.0
Opfr	20										2.0						20					2.0	2.0
Oppo									20		2.0							20	60	60		14.0	8.0
Pted										20	2.0												1.0
Teca								20	20		4.0		20		20						40	8.0	6.0

Table 3. Ground Cover in m^2 Quadrats

Species	1	2	3	4	5	6	7	8	9	10	Frequency	11	12	13	14	15	16	17	18	19	20		Grand Mean
Agin	0.6	T			.01	.6		T	.3		.15										.4	.04	.09
Agsm									T		T		1.6	.4	.2	1.01	.2	.2	.4	.5	2.8	.73	.36
Agtr	5.6	.4	.3	3.6	.3	1.7	2	3.8	.6	.6	1.89		.4			.4	1.6					.24	1.06
Bogr									.3		.03												.02
Brte 1																T		T	T				T
Fear 1									.4		.04			.3		.2			T			.05	.04
Kocr	.4		T		T	.2	1.3	T	.4	.3	.26	.3	1	.2	T	.3	.5			T	.4	.27	.26
Orhy	.01	.8	.2	1.01	.4	.3	.3	.01	.9	.01	.39	1.7	.4	T	.4	.9	1.01	T		1.6		.60	.50
Pofe	.01		T								T				T				T		.2	.02	.01
Posa 1	T	T	T				T		T	T	T	T	T	.2	T	T	.4	T	.01	T	T	.06	.03
Sihy	.45		.4		T						.08	.7	.3		.2	.4	.9	1	1.9	T	.3	.57	.32
Stco 1	6.6	1.2	.5	T	2.9	.8			.8	2.3	1.51	.6	1.4	5.4	4.1	1.6	T		T	2.4	2.5	1.80	1.65
Cage 1									.2		.02				T							T	.01
Anro								T			T												
ASIE	T		T		.2	T		T	.01	T	.02			T	T	T			T	T	T	T	.01
Asdi										T	T												T
Aspu																.2				T		.02	.01
Chal 1																		T				T	T
CHEN	T										T												T
Crse	.8	.9	1.3	.4	1.4	.2	.2	1.3	T	T	.65						.5					.05	.35
OALE															.5							.05	.02
OLSC 1					T						T							T				T	T
ERIG	T										T												T
Eral		T									T												T
Erlo 1		.6									.06												.03
Eufe						.01					T												T
HAPL			T								T												T
Haac				1.6		T					.16	T		T								T	.08
Hanu	T	T			T	.4	.2	.4	.01	T	.10	T				T				T	T	T	.05
Hyri		T									T												T
Ipag													.2									.02	.01
Ipco	T	.01	.4	.2		T	.01	.01	.01	T	.06	T										T	.03
Lepu							.2	T			.02												.01
Oxla				.2						.6	.08												.04
PENS									T		T						T			T		T	T
Phho	.3	.8	.8	.8	2	1.4	.5	.2	.4	1	.82	2.9	1.7	2.9	1.7	.2	4.4			2.6	1.5	1.79	1.30
Phlo		1.3	.2	T	.2	T					.17												.08
Phmu						.01	.9	.01			.09									T		T	.04
Phil	T			T		T	T	T		.01	T												T
Semu			.2	T	.01	.01	T	.01	.01	T	.02												.01
Sial					T						T												T
Spco 1	T								.7		.07		.01	T	T		T	T		T	T	T	.04
TOWN							.7		.01		.07			T	T						T		.04
Trgy									T	T	T											T	T
Artr	22.6	6.6	14	6	5	10.6		21.2	6.6	7.6	10.02	17.4	18.8	9.8	19.6	32.2	41	23.8	34	6.4	12.2	21.52	15.77
									2		.2												
Chra																	.6					.06	.03
Chvi 3																							
Gusa			.4		T	.8	T	.01		T	.12	.8						.2		.2	.4	.16	.14
Juos									T	12	1.20												.60
Opir	T										T						T					T	T
Oypo									.6		.06							.4	2	.6		.3	.18
Pied										1.8	.18												.09
Teca								.2	T		.02		.2		T						.2	.04	.03

Table 4. Biomass in Pinyon-Juniper Community
1/10 m quadrats (100 samples)

Species	Green/Weight kg/ka	Dry Weight kg/ka	% Total Biomass	Frequency
GRASSES				
Agropyron smithii	9.5	6.8	1.8	8.0%
A. spicatum inerme	11.0	6.8	1.8	2.0%
A. trachycaulum	59.5	30.3	8.0	25.0%
Koeleria cristata	15.5	11.9	3.1	11.0%
Oryzopsis hymenoides	15.5	12.1	3.2	9.0%
Poa secunda	6.0	(5.0)*	1.3	6.0%
Stipa comata	74.0	51.8	13.7	27.0%
FORBS				
Arenaria fendleri	2.5	2.0	0.5	4.0%
Astragalus diversifolius	1.0	(0.8)*	0.2	1.0%
Cryptantha sericea	30.0	24.0	6.3	30.0%
Eriogonum alatum	2.0	(1.6)*	0.4	1.0%
Erigeron eatonii	0.5	(0.4)*	0.1	1.0%
Euphorbia fendleri	1.5	0.9	0.2	3.0%
Haplopappus acaulis	18.5	16.5	4.4	4.0%
H. nuttallii	19.0	10.6	2.8	12.0%
Ipomopsis congesta	6.5	3.4	0.9	5.0%
Phlox hoodii	17.0	15.3	4.0	17.0%
P. longifolia	6.5	(5.0)*	1.3	11.0%
P. multiflora	4.0	(2.5)*	0.7	3.0%
Physaria floribunda	3.0	(2.0)*	0.5	5.0%
Senecio multilobatus	16.5	11.2	3.0	16.0%
Townsendia incana	1.5	1.0	0.3	3.0%
SHRUBS				
Artemisia tridentata	233.0	111.8	29.5	15.0%
Chrysothamnus viscidiflorus	8.0	4.6	1.2	4.0%
Opuntia polyacantha	146.0	32.1	8.5	3.0%
Tetradymia canescens	13.0	8.2	2.1	1.0%

Table 5. Biomass in Sagebrush Community -- mid-August, 1976
1/10 m quadrats (200 samples)

Species	Green/Weight kg/ka	Dry Weight kg/ka	% Total Biomass	Frequency
GRASSES				
Agropyron smithii	91.25	65.7	11.12	52.5%
A. spicatum inerme	3.25	2.0	0.3	2.0%
A. trachycaulum	14.75	7.5	1.3	4.0%
Bouteloua gracilis	0.25	(0.1)*	0.0	0.5%
Bromus tectorum	0.25	(0.2)*	0.0	0.5%
Festuca arizonica	3.50	(2.0)*	0.3	2.0%
Koeleria cristata	8.25	6.4	1.1	6.5%
Oryzopsis hymenoides	32.00	25.00	4.2	13.5%
Poa fendleriana	0.50	(0.3)*	0.0	0.5%
P. secunda	10.50	(8.0)*	1.4	17.5%
Sitanion hystrix	9.50	(6.5)*	1.1	8.5%
Stipa comata	61.25	42.9	7.3	36.0%
FORBS				
[illegible]enaria fendleri	0.25	0.2	0.0	0.5%
[illegible]haenactis douglasii	0.25	(0.1)*	0.0	0.5%
Cryptantha sericea	1.75	1.4	0.2	2.5%
Erigeron eatonii	4.75	(3.5)*	0.6	7.5%
Eriogonum alatum	1.00	(0.6)*	0.1	0.5%
Haplopappus acaulus	0.50	0.3	0.0	0.5%
H. ruttallii	5.50	3.1	0.5	1.5%
Ipomopsis congesta	0.25	0.1	0.0	0.5%
Linum lewisii	0.50	(0.4)*	0.1	0.5%
Oxytropis lambertii	6.00	2.8	0.5	0.5%
Phlox hoodii	37.75	34.0	5.8	31.0%
P. longifolia	3.00	(2.3)*	0.4	5.5%
Physaria floribunda	0.25	(0.1)*	0.0	0.5%
Senecio multilobatus	0.25	0.2	0.0	0.5%
Sphaeralcea coccinea	11.00	5.2	0.9	10.5%
Trifolium gymnocarpon	0.25	(0.1)*	0.0	0.5%
SHRUBS				
Artemisia tridentata	543.25	277.1	46.9	44.0%
Chrysothamnus viscidiflorus	32.75	19.0	3.2	6.5%
Eurotia (Ceratoides) lanata	5.75	3.5	0.6	1.5%
Opuntia polyacantha	249.00	54.8	9.3	2.5%
Sarcobatus vermiculatus	43.00	12.9	2.2	1.5%
[illegible]tradymia canescens	3.50	2.2	0.4	1.0%

Table 6. Line Intercept Data
30 m Transects

Pinyon-Juniper Community

Transect No.	Species	Total Intercept	% Cover
1	*Artemisia tridentata*	8.07 m	26.9%
	Chrysothamnus nauseosus	0.19	0.6
	Eurotia (Ceratoides) lanata	0.16	0.5
	Juniperus osteosperma	6.85	22.8
2	*Artemisia tridentata*	0.50	1.7
	Juniperus osteosperma	0.80	2.7
	Pinus edulis	11.19	37.3
3	*Artemisia tridentata*	11.54	38.5
	Juniperus osteosperma	8.23	27.4
	Pinus edulis	2.73	9.1
4	*Artemisia tridentata*	1.62	5.4
	Juniperus osteosperma	6.79	22.6
5	*Artemisia tridentata*	3.58	11.9
	Juniperus osteosperma	6.57	21.9
6	*Artemisia tridentata*	4.82	16.1
	Juniperus osteosperma	8.24	27.5
7	*Juniperus osteosperma*	4.89	16.3
8	*Artemisia tridentata*	4.59	15.3
	Juniperus osteosperma	11.03	36.8
9	*Artemisia tridentata*	3.92	13.1
	Chrysothamnus nauseosus	0.32	1.1
	Juniperus osteosperma	1.36	4.5
	Pinus edulis	2.18	7.3
10	*Artemisia tridentata*	1.18	3.9
	Juniperus osteosperma	4.41	14.7
	Pinus edulis	3.73	12.4

Summary of Pinyon-Juniper Line Intercept Data

Species	Total Intercept	Mean Intercept	Mean % Cover
Artemisia tridentata	39.82	3.98	13.3
Chrysothamnus nauseosus	0.32	0.03	0.1
C. viscidiflorus	0.19	0.02	0.1
Eurotia (Ceratoides) lanata	0.16	0.02	0.1
Juniperus osteosperma	59.17	5.92	19.7
Pinus edulis	19.83	1.98	6.6
Totals	119.49	11.95	39.9

Table 6. (Continued)

Sagebrush Community

Transact No.	Species	Total Intercept	% Cover
11	*Artemisia tridentata*	5.21 m	17.4%
	Chrysothamnus nauseosus	1.08	3.6
	Gutierrezia (Xanthocephalum) sarothrae	0.14	0.5
12	*Artemisia tridentata*	6.49	21.6
13	*Artemisia tridentata*	5.95	19.8
14	*Artemisia tridentata*	5.58	18.6
	Chrysothamnus viscidiflorus	0.19	0.6
	Tetradymia canescens	0.13	0.4
15	*Artemisia tridentata*	8.82	29.4
16	*Artemisia tridentata*	7.27	24.2
17	*Artemisia tridentata*	9.86	32.9
18	*Artemisia tridentata*	11.91	39.7
19	*Artemisia tridentata*	5.53	18.4
20	*Artemisia tridentata*	3.31	11.0
	Gutierrezia (Xanthocephalum) sarothrae	0.21	0.7
	Sarcobatus vermiculatus	0.29	1.0

Summary of Sagebrush Line Intercept Data

	Total Intercept	Mean Intercept	Mean % Cover
Artemisia tridentata	69.93	6.99	23.3
Chrysothamnus nauseosus	1.08	0.11	0.4
C. viscidiflorus	0.19	0.02	0.1
Gutierrezia sarothrae	0.35	0.03	0.1
Sarcobatus vermiculatus	0.29	0.03	0.1
Tetradymia canescens	0.14	0.01	--
Totals	71.98	7.19	24.0

TABLE 7
COLORADO STATE UNIVERSITY
SOIL TESTING LABORATORY
SOIL REPORT

Lab. No.	Sample No.	pH Saturated Paste	Cond.	O. M.	NO_3-N	$NaHCO_3$ P	NH_4-AC K	Zn	Fe	Lime	Texture	Cu	Mn
			mmhos/cm	%	ppm	ppm	ppm	ppm	ppm				
1421	Rt.1	8.2	0.4	1.9	6	1	88	0.3	2.3	High	LS	0.32	2.4
1422	Rt.2	7.8	5.6	1.2	5	4	78	0.2	3.0	High	CL	0.42	2.6
1423	Rt.3	8.1	0.5	1.9	6	1	85	0.2	2.2	High	LS	0.36	1.8
1424	Rt.4	8.2	0.5	2.0	6	2	73	0.2	3.1	High	LS	0.58	2.8
1425	Rt.5	8.0	0.7	1.5	5	1	50	0.3	2.7	High	SCL	0.48	2.4
1426	Rt.6	7.8	0.3	1.5	4	2	80	0.3	3.1	High	SL	0.48	2.0

	meq/a - sat. extract Ca	Mg	Na	SAR
1422	26.4	6.9	38.6	9.5